

FINAL

**CALTRANS LAKE TAHOE
STORM WATER TREATMENT
PILOT PROJECT**
JAR TEST RESULTS AND SUMMARY REPORT
VOLUME 1 OF 3

CTSW-RT-03-063.33.41

JUNE 2003



Prepared for:
CALIFORNIA DEPARTMENT OF TRANSPORTATION
1120 N STREET
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Executive Summary

Executive Summary

The National Pollutant Discharge Elimination System Statewide Storm Water Permit (NPDES No. CAS000003) issued to the California Department of Transportation (Caltrans) requires that Caltrans meet all applicable provisions in the California Regional Water Quality Control Board, Lahontan Region, Basin Plan. The storm water permit specifies that by 2008, projects in the Lake Tahoe Basin must be retrofit with treatment systems, as necessary, to meet numeric effluent limitations for turbidity, nitrogen, phosphorus, iron, and oil and grease. As part of efforts to meet these requirements for storm water leaving Caltrans roads in the Lake Tahoe Basin, Caltrans has implemented the Lake Tahoe Small-Scale Storm Water Treatment Pilot Study. This study is designed to assess the performance of various storm water runoff treatment systems, including the use of coagulant treatment and innovative filter media (Caltrans, 2001a and 2001b).

The Lake Tahoe Small-Scale Storm Water Treatment Pilot Study consists of two phases: the Jar Testing Study and the Pilot Study. The purpose of the Jar Testing Study is to identify and select the most promising coagulants for use in the subsequent Pilot Study. The purpose of the Pilot Study is to test the effectiveness of the selected coagulant and dose (in conjunction with sedimentation and/or filtration) as a means to treat roadway storm water runoff so that the quality of storm water discharges meets Basin Plan standards. The findings of the Jar Testing Study are contained in this report.

Chemical coagulation can improve the removal of particle-associated pollutants in storm water by forming settleable and/or filterable flocs. Coagulants can also remove some dissolved pollutants, primarily phosphate, by chemical precipitation and adsorption. Of the many coagulant available, the most promising coagulants and respective doses were determined by three sets of laboratory-scale jar test experiments. For the laboratory-scale jar test experiments, storm water collected from storm water basins located at the Caltrans South Lake Tahoe Maintenance Station in Meyers, California was used. In these jar test experiments, 1) the coagulant was added to a sample of storm water, 2) the sample was mixed well, 3) the sample was allowed to settle for 30 minutes, and 4) the supernatant produced by the settling process was analyzed to determine the treatment effectiveness of the tested coagulant type and coagulant dose. Slow mixing, which is often included in standard jar test procedures, was not done because of doubts that slow mixing can be achieved in field-scale facilities.

The first set of experiments consisting of 120 preliminary jar tests was used to evaluate thirteen different coagulants. In these preliminary jar tests, the criterion measured for performance evaluation was turbidity reduction, which is a general and inexpensive measure of treatment performance potential. These tests provided the information needed

1) to reduce the number of study coagulants from thirteen to six, 2) to determine appropriate dose ranges for further study, and 3) to estimate coagulant alkalinity requirements. The six most promising coagulants retained for further study based on preliminary jar test results were aluminum sulfate (alum), ferric chloride, JC 1670, Pass C, Superfloc A1849, and Westchlor 950S. This group of coagulants includes two conventional metallic salt coagulants, three polyaluminum coagulants, and an anionic polyacrylamide polymer, respectfully.

The second set of experiments consisted of 56 jar tests performed with the coagulants and dosage ranges selected from the first set of preliminary jar tests. In this second set of jar test experiments, coagulant performance was evaluated based on a comprehensive suite of water quality parameters including solids (turbidity and total suspended solids), nutrients (ammonia, nitrate, nitrite, TKN, phosphate, and phosphorous), metals (aluminum, chromium, copper, iron, lead, and zinc), and other conventional parameters (hardness, pH, alkalinity, specific conductance, and total dissolved solids). The tests were run at two temperatures, 4°C and 15°C (40°F and 60°F), corresponding to winter and summer temperatures measured in the Upper Truckee River. Through evaluation of these experimental results, the coagulant and dose with the greatest overall pollutant reduction under variable temperature conditions were determined. The results from this second set of jar test experiments identified differences between coagulants and doses, but did not clearly delineate the effects of temperature on coagulant treatment performance.

The storm water used in the second set of jar test experiments did not contain adequate concentrations of phosphate to fully evaluate the phosphate removal performance differences between the coagulants and doses tested. Consequently, a third set of experiments was undertaken to study storm water phosphate removal. In these jar test experiments, the storm water samples were spiked with 1 mg/L of phosphate. The storm water used in these tests also had a higher salinity content (ionic strength) than that used in the earlier tests, which allowed some insight into the potential effects of road salt on coagulant performance.

The overall result of the Jar Testing Study was the conclusion that Pass C dosed at 100 mg/L (on a whole product dose basis) was the coagulant and dose that most improved storm water quality. This coagulant at this dose was ranked highest in solids removal, nutrients removal, and metals removal. Additionally, the results of the phosphate-spiking experiments supported the conclusion that Pass C dosed at 100 mg/L was the most promising coagulant. Westchlor 950S and JC 1670, both polyaluminum chloride compounds, were the two next best performing coagulants. Both aluminum sulfate and ferric chloride consumed alkalinity requiring the addition of sodium hydroxide to maintain storm water pH values between 6 and 7, and to achieve the reported treatment effectiveness. Superfloc A1849 generally performed poorly when compared to the other coagulants tested. Based on these findings, Pass C was selected for Pilot Study use.

Chapter 1

Introduction

Chapter 1 Introduction

The treatment of storm water in the Lake Tahoe Basin is being studied as part of the overall effort to reduce the pollution load on Lake Tahoe, and thereby slow, if not reverse, the current trend of decreasing lake clarity. Storm water contaminants of major concern have been identified by the California Regional Water Quality Control Board, Lahontan Region (hereafter, Regional Board). These contaminants and the numeric limits on these contaminants for storm water discharges to surface waters in the Lake Tahoe Basin are presented in Table 1-1. Storm water from Caltrans roads is required to comply with Table 1-1 storm water limitations pursuant to the NPDES Permit for Storm Water Discharges from Caltrans Properties, Facilities, and Activities (State Water Resources Control Board Order No. 99-06-DWQ).

Table 1-1. Lake Tahoe Basin Numeric Storm Water Discharge Limits

Primary Pollutants of Concern	Lake Tahoe Basin Water Quality Objectives (a)
	Maximum Surface Water Concentrations
Total Nitrogen (as N)	0.5 milligrams per liter (mg/L)
Total Phosphate (as P)	0.1 mg/L
Total Iron (Fe)	0.5 mg/L
Turbidity	20 nephelometric turbidity units (NTU)
Oil and Grease	2.0 mg/L

(a) Data source: LRWQB, 1994.

The current best apparent alternatives for complying with the Table 1-1 limits on storm water quality from roads include:

- Enhanced preventative operation and maintenance of the roads.
- Storm water treatment.

Chemical coagulation of storm water followed by filtration is the technologically most sophisticated, realistic method to attempt to meet the numeric limits for storm water discharges in the Lake Tahoe Basin. The chemical coagulation step is necessary to, in essence, “glue” many of the very small contaminant particles together into large particles that, then, can be removed by filtration.

While the storm water filtration process (a physical straining/screening process) is reasonably well understood, the storm water chemical coagulation process (involving complex chemical interactions) is not well understood under the varying temperature, pH, salinity, and general water quality conditions encountered in storm water from roads. To better understand the complex chemical interactions involved with chemical coagulation of

Lake Tahoe Basin storm water runoff from roads, the Jar Testing Study phase of the overall Caltrans Lake Tahoe Small-Scale Storm Water Treatment Pilot Project was developed and completed prior to embarking on field-scale storm water treatment trials (Pilot Study).

The Jar Testing Study began on 30 October 2001. The purposes of the Jar Testing Study phase of the overall project were to select 1) the most promising storm water chemical coagulants from the many coagulants with storm water treatment potential based on available literature, and 2) the most promising doses for these coagulants. The most promising coagulant and dose were used in the second phase of the project (the Pilot Study phase) involving field-scale storm water treatment trials under simulated field conditions.

The Jar Testing Study consisted of three sets of experiments: 1) preliminary jar tests to narrow the number of coagulants under consideration from thirteen to six based on five dosing concentrations for each coagulant; 2) variable temperature experiments conducted at 4°C and 15°C with each of the six coagulants at all five doses selected to investigate contaminant removal efficiency as a function of temperature; and 3) phosphate-spiked/high salinity experiments to investigate a) the removal of phosphate (a contaminant of significant concern in the Lake Tahoe Basin relating to eutrophication effects), and b) possible effects of road salt on coagulant treatment performance.

The storm water used for the Jar Testing Study was collected from storm water detention basins located at the Caltrans South Lake Tahoe Maintenance Station in Meyers, California on three dates: 30 October 2001, 13 November 2001, and 12 December 2001. Storm water runoff from the South Lake Tahoe Maintenance Station reasonably represented “worst-case” storm water from a water quality perspective in the Lake Tahoe Basin because of the amount of traffic, equipment, and road materials at the maintenance station.

The storm water collected at Caltrans South Lake Tahoe Maintenance Station on each of these dates had different chemical/physical properties. The 30 October 2001 storm water was very turbid and had relatively low specific conductance (800 NTU and 800 µmhos/cm, respectively). This storm water may represent “first flush” storm water after a protracted dry period. The 13 November 2001 storm water was much less turbid and also had low specific conductance (100 NTU and 200 µmhos/cm, respectively). This storm water may be typical of storm water following “first flush” events. The 12 December 2001 storm water had moderate turbidity and high specific conductance, reflective of road salts and sands applied in the Lake Tahoe Basin (400 NTU and 9,000 µmhos/cm, respectively).

Storm waters collected on 30 October 2001 (herein labeled the “Batch I” storm water) and on 13 November 2001 (the “Batch II” storm water) were used in the first set of jar test experiments (i.e., preliminary jar tests) to narrow the number of coagulants under consideration from thirteen to six. Batch III storm water, which was a blend of Batch I and

Batch II storm water, was used for the second set of experiments conducted at 4°C and 15°C to study temperature effects on overall coagulant performance to remove solids, nutrients, metal, etc. Batch IV storm water (from 12 December 2001) was used for the phosphate-spiked/high conductance experiments, i.e., the third set of experiments.

The three sets of experiments conducted are summarized in Table 1-2 with the number of coagulants tested, experimental temperature, water source, constituents tested and general comments regarding the experiments indicated, therein.

Table 1-2. Jar Testing Study Summary of Experiments

Experiment	Number of Coagulants Tested	Temperature	Water Source	Constituents Tested	Comments
First Set: Preliminary Coagulant Evaluation	13	4°C - 10°C	Batch I and Batch II	Turbidity	Used to reduce the number of coagulants under consideration.
Second Set: Temperature Effects on Coagulant Performance	6	4°C	Batch III	Full scan (a)	Used to evaluate effectiveness of coagulants and doses.
	6	15°C	Batch III	Full scan (a)	Used to evaluate temperature impact on effectiveness (paired with 4°C results).
Third Set: Phosphate-Spiked/ High Salinity	6	4°C	Batch IV	Full scan (a)	Used to evaluate phosphate removal effectiveness.

(a) The “full scan” constituents tested list includes solids, nutrients, metals, and conventional parameters and is presented in Table 3-1 with the analytical methods used. Oil and grease removal performance was not tested during this study because two liters of sample is required for the oil and grease analysis and laboratory-scale jar tests sample volumes were limited to approximately 1.1 liter which was needed for the analyses of the “full scan” constituents.

The monitoring data collected during this first set of experiments are presented in Appendix A. The untreated and control sample results obtained during the comprehensive temperature and phosphate-spike experiments are presented in Appendix B. The coagulants and doses tested, with the corresponding data reports for the temperature and phosphate-spike studies, are summarized in Appendix C. The original hard-copy reports that were received are included in Appendix H, which is a separately bound attachment to this report.

1.1 Experimental Methods

The jar testing protocol was described in a previously issued report (Caltrans, 2001c). Therefore, only a brief overview of the jar testing protocol is presented here (see report excerpt of protocol in Appendix F):

- Six 1,500 mL test samples were removed from the batch of storm water at a time, and placed in six individual beakers.

- The six beakers containing the test samples were placed (with magnetic stirrers) on a magnetic stir plate submerged within a temperature bath. The temperature bath was maintained at either 4°C or 15°C with a chiller/heater combination.
- A known dose of coagulant was then added to each beaker, mixed rapidly via the magnetic stirrer, and allowed to settle (i.e., stirrer off) for approximately 30 minutes.
- Following sedimentation, approximately 1,100 mL of supernatant were removed from each beaker for on-site testing and analytical laboratory testing.
- Samples of the supernatant that were to be analyzed for dissolved constituents were field filtered as an analytical preparation process using a peristaltic pump, disposable tubing, and 0.45 µm disposable capsule filters. Dissolved constituent samples are typically referred to herein as “filtered” samples.
- Samples of the supernatant that were to be analyzed for total metals underwent laboratory acid digestion as an analytical preparation process. Samples that were collected for dissolved metals analyses did not undergo acid digestion.

Untreated (termed “influent”) samples of storm water were collected and analyzed periodically to assess the variability of the batches of storm water over the time during which the various jar test experiments were conducted. Untreated samples did not undergo any sedimentation or coagulant treatment. Most daily jar test experimental sets included a control sample. The control sample was treated as all other samples, i.e., the control sample underwent rapid mixing and sedimentation, except that no coagulant was added to the sample.

Statistical analyses of the untreated and control samples were performed using the Caltrans Data Analytical Tool (DAT) program and are presented in Appendix D for those samples in which sufficient detections to perform the analyses occurred. Additionally, statistical tests of the means from the untreated and control datasets were performed to evaluate the effects of sedimentation. SigmaStat® was used to perform parametric and non-parameter (when the results were not normally distributed) statistical analyses. These statistical data reports are summarized and presented in Appendix D. The statistical findings from the tests of means are noted in tables presenting the Caltrans DAT statistics.

1.2 Coagulant Dose Determinations

The coagulant doses tested can be described in several different ways. Doses can be expressed as supplied product, as dry product, as mg/L of the metal in the coagulant, etc. For many of the coagulants studied, including polyaluminum chloride, aluminum sulfate (hydrated), ferric chloride (hydrated), and polyacrylamides, dose can only be expressed meaningfully in terms of “supplied product” because of the complex chemical nature and formulations of the coagulant as supplied. Consequently, all coagulant doses reported,

herein, are in terms of supplied product. Product information for the thirteen coagulants tested are presented in Appendix G, which is a separately bound attachment to this report.

1.3 Evaluation Criteria

For the first set of preliminary jar test experiments designed to screen the general effectiveness of thirteen different coagulants, field-measured turbidity was used as the primary indicator of treatment performance. Since the experiments were conducted for screening purposes only, samples were not submitted to the laboratory for chemical analyses. For the second and third sets of experiments involving more thorough evaluation of the six most promising coagulants and doses, coagulant performance was evaluated based on storm water quality improvement in five pollutant categories:

- Solids
- Nutrients
- Metals
- Aluminum
- Conventional parameters

The solids category includes totals suspended solids (TSS) and turbidity (a regulated parameter, see Table 1-1). The nutrient category includes nitrogen compounds and phosphorous compounds, many of which are regulated in the Lake Tahoe Basin (see Table 1-1). The nitrogen compounds include ammonia, nitrate, nitrite, and Total Kjeldahl Nitrogen (TKN). The phosphorous compounds include phosphorous and phosphate. The metals category includes aluminum, chromium, copper, iron, lead, and zinc. Although metals are not regulated in the Lake Tahoe Basin at this time (except for iron, a micronutrient biostimulant), metals removal from storm water is considered an important performance parameter. Aluminum is a separate evaluation category because many of the coagulants are aluminum-based compounds, and thus could contribute to residual aluminum concentrations in storm water discharges. Aluminum can be toxic to aquatic life. The conventional parameters category includes hardness (i.e., calcium and magnesium), pH, alkalinity, specific conductance (commonly referred to as electrical conductance or EC), and total dissolved solids (TDS). These parameters were monitored for a number of reasons: 1) the toxicity of many metals is dependent on water hardness, 2) alkalinity affects coagulant performance and pH, 3) pH affects coagulant performance and the toxicity of many metals, and 4) EC and TDS are indicators of the total salt content of the water.

Chapter 2

Preliminary Jar Test Experiments

Chapter 2 Preliminary Jar Test Experiments

The thirteen coagulants listed in Table 2-1 were evaluated in the preliminary jar test experiments. In these preliminary experiments, a total of 120 individual jar tests were conducted over the course of a one-month period.

Three categories of coagulants were identified in a literature review conducted by Caltrans (Caltrans, 2001a) and subsequently evaluated during the Jar Testing Study: conventional metallic salt coagulants, polyaluminum chloride coagulants, and polyacrylamide polymer coagulants. Aluminum sulfate and ferric chloride are conventional metallic salt coagulants having a long history in water treatment. Polyaluminum chloride coagulants are newer metallic salt coagulants that have been “pre-polymerized”, and consequently do not require as much alkalinity addition during the coagulation process. Polyacrylamide coagulants are high molecular weight, complex organic polymers which require “re-activation” to unfold the molecule prior to use, but require very little product to enhance sedimentation through flocculation. Additional background information regarding the coagulants tested is included with the jar test protocol (see Appendix F). Coagulant product information is presented in Appendix G, which is a separately bound attachment. The use of these coagulants in the Lake Tahoe Basin under winter freezing conditions was a factor considered when selecting the specific coagulants within each of the three categories. Issues related to freezing conditions are 1) the temperature effects on the usability of the coagulants, and 2) if useable, temperature effects on the performance of the coagulant.

Table 2-1. Treatment Coagulant Used in Preliminary Jar Tests

Coagulant	Type	Manufacturer
Aluminum Sulfate	Aluminum Sulfate	General Chemical
Ferric Chloride	Ferric Chloride	Eaglebrook
JC 1600	Polyaluminum Chloride-Polymer Blend	JenChem
JC 1670	Polyaluminum Hydroxchloride-Polymer Blend	JenChem
JC 1679	Polyaluminum Chloride-Polymer Blend	JenChem
JC 1820	Polyaluminum Hydroxchloride	JenChem
PAC-300	Polyaluminum Chloride	Summit Research Labs
Pass-C	Polyaluminum Chloride	Eaglebrook
Sumaclear 700	Polyaluminum Chloride	Summit Research Labs
Sumalchlor 50	Polyaluminum Chloride	Summit Research Labs
Superfloc A1849	Anionic Polyacrylamide	Cytec
Superfloc C1598	Cationic Polyacrylamide	Cytec
Westchlor 950S	Polyaluminum Hydroxchlorosulfate	Westchlor

2.1 Coagulant Dose Ranges Studied in Preliminary Jar Testing

Preliminary jar tests using all of the coagulants and doses within the ranges indicated in Table 2-2 were first conducted using Batch I storm water, which as indicated previously, had a turbidity of 800 NTU. To assess appropriate dose adjustments for less turbid storm water, additional preliminary jar tests using only alum and JC 1670 and Batch II storm water (with a turbidity of 100 NTU) were conducted.

Table 2-2. Preliminary Jar Test Coagulant Concentrations Studied

Coagulant	Number of Jar Test	Minimum Dose (mg/L)	Maximum Dose (mg/L)	NSF Maximum Dose (mg/L) (a)
Aluminum Sulfate (alum)	24	13	2,670	150
Ferric Chloride	6	14	687	250
JC 1600	6	67	2,152	250
JC 1670	20	13	1,032	100
JC 1679	8	12	2,480	62
JC 1820	6	31	500	250
PAC-300	6	60	1,912	250
Pass-C	4	31	248	250
Sumaclear 700	8	33	2,640	250
Sumalchlor 50	7	13	2,670	250
Superfloc A1849	6	0.1	3.5	3.5
Superfloc C1598	6	0.05	2.5	2.5
Westchlor 950S	7	13	524	250
None (Control Sample)	6	0.00	0.00	---

(a) NSF Maximum Dose – Dose set by the National Sanitation Foundation to avoid causing adverse human health effects.

2.2 Preliminary Jar Test Results, and Coagulants and Concentrations Selected for Further Jar Tests

Turbidity and “floc response” (i.e., formation of a flocculant settling mass) were the two parameters monitored during the preliminary jar tests to select coagulants for further study. The need of some coagulants for the addition of NaOH to maintain near neutral pH (6 to 7) conditions was also monitored. The results from field monitoring are summarized in Appendix A. As these were preliminary jar tests, when there was no indication of turbidity reduction, turbidity was not measured. Mixing and sedimentation times varied somewhat over the course of the 120 preliminary jar tests as indicated in Appendix A. Mixing times (on the order of seconds) varied during these tests while laboratory experience dosing six beakers in a short period of time was gained. Sedimentation times were allowed to vary in response to the visual performance of the

coagulant in the preliminary jar test. As examples, if results indicated that the coagulant and dose were ineffective, then the test was quickly aborted; or if it appeared that more time than 30 minutes was needed for floc development, then additional time was allowed and noted. The coagulants requiring NaOH addition to maintain storm water pH in the 6 to 7 range included aluminum sulfate (alum), ferric chloride, Sumalchlor 50, Sumaclear 700, PAC 300, JC 1600, JC 1670, JC 1820, JC 1679, and Westchlor 950S. To minimize the number of necessary jar tests, if during a jar test the pH values decreased immediately to below 6.0, then there was no need to perform a separate test of the coagulant without alkalinity addition. Special testing with aluminum sulfate was needed to develop an estimation of alkalinity requirements. More testing was needed for aluminum sulfate than for ferric chloride to estimate requirements, even though both required substantial NaOH additions in all but the lowest doses tested. However, NaOH was only needed at the higher doses tested for JC 1679 and Westchlor 950S.

The results from the preliminary jar tests using Batch I and Batch II storm indicated 1) the potential for adverse effects from over-dosing for at least one coagulant, and 2) turbidity reductions differed with high turbidity storm water versus low turbidity storm water. These factors suggest that some type of coagulant dose control, perhaps based on turbidity or zeta potential (as measured in a streaming current meter), may be needed to optimize performance in field applications once more is known about coagulant responses to storm waters of different qualities.

The coagulants that reduced turbidity and formed floc within the 30 minutes at doses not exceeding maximum NSF concentrations included aluminum sulfate, Pass C, Westchlor 950S, ferric chloride, JC 1820, JC 1679, and JC 1670 representing two of the three coagulant categories (conventional metallic salt coagulants and polyaluminum chloride coagulants). A determination was made that all three categories would be tested further; consequently, Superfloc A1879 (the better of the two polyacrylamide polymer coagulants) was selected for further testing.

Only six coagulants could be tested in the second set of more comprehensive jar tests. Thusly, other factors such as usage history, NaOH addition, and observations during testing were considered to reduce the field of coagulants for comprehensive jar testing to six. Aluminum sulfate and ferric chloride were to be included because these are conventional coagulants with a long history of use for water treatment. Pass C did not require the addition of NaOH, had favorable results at 125 mg/L (one-half the NSF dose), and represented the polyaluminum coagulant category. Superfloc A1879 was included with the six selected for further study representing the polyacrylamide coagulant category. With two coagulants left to select, Westchlor 950S and JC 1679 (both polyaluminum chloride coagulants) were selected based on a limited requirement for alkalinity adjustment (only small adjustments at the higher doses tested).

The six coagulants and dose concentrations selected are shown in Table 2-3. The minimum and maximum concentrations selected for further study (see Table 2-3) are often (but not always) lower than the corresponding boundary concentrations in the preliminary jar tests (Table 2-2). The maximum concentrations selected for further study were based on the doses approved by NSF for drinking water treatment. The lower minimum concentrations were selected based on test results, and to investigate subtler dose effects.

Table 2-3. Coagulant and Doses Selected from Preliminary Jar Test Experimental Results

Coagulant	Doses for Further Study (mg/L)					NSF Maximum Dose (mg/L) (a)
Aluminum Sulfate	5	20	50	100	150	150
Ferric Chloride	5	20	50	100	250	250
JC 1670	2	5	20	50	100	100
Pass C	5	20	50	100	250	250
Superfloc A1849	0.5	1.0	1.5	2.5	3.5	3.5
Westchlor 950S	5	20	50	100	250	250

(a) NSF Maximum Dose – Dose set by the National Sanitation Foundation to avoid causing adverse human health effects.

Chapter 3

Comprehensive Jar Tests Conducted at 4 and 15 Degrees Celsius

Chapter 3 Comprehensive Jar Tests

Conducted at 4° and 15° Celsius

The six selected coagulants (aluminum sulfate, ferric chloride, JC 1670, Pass C, Superfloc A1849, and Westchlor 950S) were tested to evaluate the ability of these coagulants to improve storm water quality for a wide range of water quality parameters at 4°C and at 15°C, at the dose ranges identified in Table 2-3, and with 30 minutes of sedimentation following treatment. These tests were conducted using Batch III storm water, which was a blend of Batch I and Batch II storm water.

Due to the limited volume of Batch III storm water available, not all of the tests conducted at 4°C could be repeated at 15°C. Each of the six coagulants was tested at 15°C tests, but using only two dose concentrations. For five of the six coagulants, the two dose concentrations tested at 15°C were 1) the dose concentration showing the greatest decrease in turbidity at 4°C, and 2) the next lowest dose concentration. For Superfloc A1849 with a very low NSF maximum dose of 3.5 mg/L and with anticipated field dosing difficulties, the two concentrations tested were those with the greatest decrease in turbidity at 4°C that were below the maximum NSF dose.

The Appendix C index 1) lists all of the samples collected from the comprehensive jar test experimental trials conducted at 4°C and 15°C (Trials 22-33), and the jar test trials conducted at 4°C using phosphate-spiked storm water (Trials 34-36), and 2) identifies the samples by chemical coagulant and dose used, experimental temperature, trial number, storm water used, jar test date (date of sample collection), on-site sample name, laboratory identification number, laboratory report date, and date of a revised laboratory report, if a revised report was issued.

Thirty-four water quality parameters were monitored in this comprehensive jar test phase, including two solids, twelve metals, ten nutrients, and ten conventional water quality parameters. These water quality parameters, analytical methods, and laboratory reporting limits used in this study are presented in Table 3-1. Appendix C contains the analytical results summary reports for these jar test experiments. Appendix H (bound as a separate document) includes copies of the original laboratory reports that were provided by the laboratory in hard copy. Laboratory reports that were only provided electronically are included in printed form in Appendix H for reference, but are formatted differently than the original mailed or faxed reports.

Table 3-1. Parameters Measured in Comprehensive Jar Test Study

Parameters	Analytical Method	Reporting Limit
Solids		
Total Suspended Solids (TSS)	EPA 160.1	1 µg/L
Turbidity	EPA 180.1	0.5 NTU
Nutrient		
Ammonia as N (NH ₃ - N), Total	EPA 350.3	0.10 mg/L
Ammonia as N, Filtered	EPA 350.3	0.10 mg/L
Nitrate as N (NO ₃ - N)	EPA 300.0	0.10 mg/L
Nitrite as N (NO ₂ - N)	EPA 300.0	0.10 mg/L
Total Kjeldahl Nitrogen (TKN), Total	EPA 351.3	0.10 mg/L
Total Kjeldahl Nitrogen, Filtered	EPA 351.2	0.10 mg/L
Ortho-Phosphate as P, Total	EPA 365.2	0.03 mg/L
Ortho-Phosphate as P, Filtered	EPA 365.2	0.03 mg/L
Phosphorus as P, Total	EPA 365.2	0.03 mg/L
Phosphorus as P, Filtered	EPA 365.2	0.03 mg/L
Metals		
Aluminum (Al), Total	EPA 200.8	10 µg/L
Aluminum, Filtered	EPA 200.8	10 µg/L
Chromium (Cr), Total	EPA 200.8	1.0 µg/L
Chromium, Filtered	EPA 200.8	1.0 µg/L
Copper (Cu), Total	EPA 200.8	1.0 µg/L
Copper, Filtered	EPA 200.8	1.0 µg/L
Iron (Fe), Total	EPA 200.7	20 mg/L
Iron, Filtered	EPA 200.7	20 mg/L
Lead (Pb), Total	EPA 200.8	1.0 µg/L
Lead, Filtered	EPA 200.8	1.0 µg/L
Zinc (Zn), Total	EPA 200.8	5.0 µg/L
Zinc, Filtered	EPA 200.8	5.0 µg/L
Conventional Parameters		
Calcium (Ca)	EPA 200.7	0.05 mg/L
Magnesium (Mg)	EPA 200.7	0.05 mg/L
Hardness as CaCO ₃ (divalent cations)	SM 2340B	1 mg/L
pH	EPA 150.1	0.1 units
Total Alkalinity	EPA 310.1	0.1 mg/L
Bicarbonate Alkalinity	EPA 310.1	0.1 mg/L
Carbonate Alkalinity	EPA 310.1	0.1 mg/L
Hydroxide Alkalinity	EPA 310.1	0.1 mg/L
Specific Conductance (EC)	EPA 120.1	1.0 µmho/cm
Total Dissolved Solids (TDS)	EPA 160.2	1 mg/L

In the remainder of this chapter, the results from the jar tests will be presented by parameter groupings listed above. The untreated and control sample results are presented separately for comparison, and to illustrate the range of variability observed. The variability in on-site measurements of pH, EC, and turbidity was less than the variability in the analytical laboratory results for these same parameters from the same samples. Possible reasons for the increased laboratory variability in the laboratory results are discussed with the presentation of the data.

Quality control/quality assurance (QA/QC) samples were collected throughout the jar testing study, and included untreated samples, control samples, field blank samples, and an equipment blank sample. The results for these QA/QC samples are presented in Appendix B. Due to the limited volume of storm water used in each jar test and the volume needed to perform the analyses, duplicate samples from a single jar test experiment could not be collected and submitted to the analytical laboratory. The untreated samples represented the initial or “influent” concentrations of monitored parameters in Trials 22 to 29 prior to treatment. The untreated samples were well mixed and were collected to minimize sedimentation during the transfer of the sample into sample containers. The seven replicate untreated samples were collected during the study, and were used for comparison with the control samples and coagulant-treated samples. The control samples were allowed to undergo sedimentation (similar to the coagulant-treated samples) to evaluate the effects of sedimentation only. Six control samples were collected during the study, and were used for comparison with the untreated samples and the coagulant-treated samples. Milli-Q water (on-site tap water that was distilled and filtered through granulated carbon and ion exchange media via the Milli-Q process) was the ultra-pure water used for field blanks. Field blanks were collected using ultra-pure water poured directly into sample containers received from the laboratory using the same techniques used to collect all other samples. An equipment blank sample was collected at the beginning of the study to evaluate the equipment decontamination procedures. The QA/QC sample results are tabulated in Appendix B and summarized in Appendix C. The laboratory reports are presented in Appendix H.

Summary statistical analyses of the untreated and control samples were performed using the Caltrans data analysis tool (DAT) that was developed to provide a uniform method for Caltrans researchers to perform summary statistical analyses of water quality datasets including non-detect results. The Caltrans DAT statistical program, in essence, approximates numerical values for analytical results based on regression relative to detected analytical results. To use the Caltrans DAT statistical program there must be at least three detected analytical results, and the detected analytical results must represent at least 20 percent of the dataset. More specifically, the Caltrans DAT statistical method uses a regression of ordered statistics that develops probability-plotting positions for each non-detect datum point based on the ordering of the data. The regression is performed using the log-transformed concentrations and the probability plotting positions. This results in an equation to calculate a value for the non-detect datum that is based on the detected data and ordered position.

The Caltrans DAT program calculates variance summary statistics using a Tukey-Jackknife algorithm, which is performed numerically by sequentially removing one point from the dataset, running the analysis, and calculating the variance estimators as the average of each of the “n” runs of data. Use of this method is necessary (instead of more typical variance analyses) because an estimation method was used to assign/approximate values for the results in the dataset that were non-detect. The statistical analyses of the resultant dataset are performed on untransformed data to avoid introducing transformation biases. Transformation biases are introduced when datasets with significant scale-dependent relationships are transformed, and then transformed back (Shumway and Azari, 2000).

The Caltrans DAT summary statistics for the untreated and control samples by parameter group are presented in Appendix D. There are numerous analytical results reported that appear anomalous; however, the analytical laboratory reporting these anomalous data has reviewed the results, and indicated that all the results presented as final are true and accurate representations of the samples submitted to the best of their knowledge. Therefore, no data were removed as “errors” prior to performing the summary statistical analyses, except as noted in the text. Based on the number of samples tested (seven untreated and six control), outlier statistical analyses were not performed. Generally ten or more replicate samples are required for outlier identification.

The Caltrans DAT program is used to calculate various summary statistics including the 95 percent confidence interval about the means for the control samples and untreated samples (Appendix D). The confidence interval is calculated using the sample standard deviation, the sample size, and the sample mean for normally distributed data. The numeric limits defining the confidence interval are calculated by adding and subtracting from the mean a standard error term associated with the degree of confidence (i.e., the 90 percent confidence interval will have a smaller range in numeric limits than the 99 percent confidence interval). The 95 percent confidence interval has an upper and lower limit within which 95 percent of the samples values are expected to lie.

The lower 95 percent confidence limit about the control sample mean for many water quality parameters monitored was used to provide a common basis for comparing pollutant removal performance for the various coagulants and doses tested. When the concentration of a pollutant after coagulant treatment was less than the lower 95 percent confidence limit for the control (sedimentation without coagulant treatment), pollutant removal due to the coagulant treatment is suggested. The use of the lower confidence limit incorporates the variability within control samples and provides a benchmark for comparative purposes. A brief description of the data uncertainty analysis is presented next.

3.1 Data Uncertainty Analysis

Uncertainty analysis involves an evaluation of the accuracy of the data. The untreated and control sample results can be used to assess uncertainties, since multiple untreated and control samples were analyzed. In fact, these samples were collected for the express purpose of assessing experimental and analytical variability from test to test. Limitations on the volume of storm water available for these studies precluded the inclusion of replicate experimental testing.

The Caltrans DAT program was used to calculate the coefficient of variation, which is a term that allows the comparison of variation between sample results. The coefficient of variation is a convenient way to compare the relative variation of two or more parameter measurements with dissimilar means. The coefficient of variation is a unitless statistical parameter that is calculated by dividing the sample standard deviation by the sample mean.

When the coefficient of variation is small, the data variability (i.e., the data scatter) is small and when the coefficient of variation is large, the amount of variation is large within the parameter dataset. Complex aqueous solutions such as storm water are characterized by an inherently variable quality relating to environmental effects such as rainfall amounts, patterns, and intensity; and watershed geology, vegetation, and land uses. Sample variation can be caused by many factors including sample constituency and sample handling. . Sample handling variability can be introduced at the time of sample collection through the time of sample analysis. The Jar Testing Study protocol (see Appendix F) identified 1) potential sources of variation, and 2) avoidance measures that were followed throughout the jar testing experiments.

The coefficients of variation for the various untreated and control parameter results are presented in Table 3-2. The parameters having coefficients of variation greater than 0.5 indicate highly variable results. The parameters with coefficients of variation greater than 0.5 include:

- Filtered aluminum (control samples).
- Filtered copper (control samples).
- Filtered iron (untreated and control samples).
- Total zinc (untreated and control samples).
- Filtered zinc (control samples).
- Total phosphorous (untreated samples).
- Laboratory turbidity (untreated and control samples).

In those cases when there were insufficient detections to obtain summary statistics using the Caltrans DAT program, the laboratory data variability was not assessed. The control and untreated sample datasets having high coefficients of variation are discussed in the following sections containing the results of the respective parameter groupings.

Table 3-2. Coefficient of Variation for the Untreated and Control Samples

Parameter Group	Parameter	Untreated (a) Coefficient of Variation	Control (b) Coefficient of Variation
Solids	Total Suspended Solids (Laboratory)	0.2	0.1
	Turbidity (Laboratory)	0.5	0.6
	Turbidity (On-site)	Data not collected	0.1
Nutrients	Ammonia, Total	Insufficient detections	0.3
	Ammonia, Filtered	Insufficient detections	Insufficient detections
	Total Kjeldahl Nitrogen, Total	0.4	0.3
	Total Kjeldahl Nitrogen, Filtered	0.3	0.4
	Nitrate	Insufficient detections	Insufficient detections
	Nitrite	Insufficient detections	Insufficient detections
	Orthophosphate, Total	Insufficient detections	Insufficient detections
	Orthophosphate, Filtered	Insufficient detections	Insufficient detections
	Phosphorous, Total	1.2	0.2
	Phosphorous, Filtered	0.2	0.4
Metals	Aluminum, Total	0.3	0.2
	Aluminum, Filtered	0.2	3.0
	Chromium, Total	0.4	0.3
	Chromium, Filtered	0.1	0.3
	Copper, Total	0.4	0.3
	Copper, Filtered	0.4	0.5
	Iron, Total	0.3	0.2
	Iron, Filtered	0.7	3.1
	Lead, Total	0.2	0.1
	Lead, Filtered	Insufficient detections	Insufficient detections
	Zinc, Total	0.5	0.5
	Zinc, Filtered	0.4	0.6
Conventional Parameters	Calcium	0.1	0.1
	Magnesium	0.2	0.2
	Hardness	0.2	0.1
	pH (Laboratory)	0.03	0.02
	Total Alkalinity	0.2	0.1
	Specific Conductance (Laboratory)	0.1	0.1
	Total Dissolved Solids (Laboratory)	0.1	0.1

Note: The Caltrans DAT program calculates summary statistics for those samples having 20 percent or more detectable values and three or more detectable values in the dataset.

(a) Untreated samples did not undergo sedimentation or coagulant treatment.

(b) Control samples did undergo sedimentation, but not coagulant treatment

3.2 Solids

During the preliminary jar tests, the removal of solids (total suspended solids and turbidity) from storm water was the main basis for deciding if a coagulant was effective at treating roadway runoff storm water. Removal of solid particles from solution is primarily what coagulants are designed to do. To a large degree, the removal of specific contaminants such as nitrogen, phosphorous, or metals depends on the effectiveness of solids removal. The objective of analyzing the “solids” parameters was to evaluate coagulant-specific removal of suspended solids under various storm water conditions that are encountered in the Lake Tahoe Basin.

The Caltrans DAT program generated untreated and control sample means and associated 95 percent confidence interval limits for total suspended solids and turbidity results are presented in Table 3-3. “On-site turbidity” results summarized in Table 3-3 are from field measurements of turbidity made immediately after a jar test experiment was completed at the time that samples were collected for subsequent laboratory analyses. “Laboratory turbidity” results summarized in Table 3-3 are from the analytical laboratory’s analysis of turbidity in the samples collected at the time that “on-site turbidity” was measured.

Table 3-3. Untreated and Control Solids Sample Statistics: Means and 95 Percent Confidence Limits

Sample	Total Suspended Solids (mg/L)		Laboratory Turbidity (NTU)		On-Site Turbidity (NTU)	
	Mean (a)	95% Confidence Limit	Mean (b)	95% Confidence Limit	Mean (c)	95% Confidence Limit
Untreated	232	195 to 270	127	84 to 170	---	---
Control	185	169 to 200	124	63 to 186	348	321 to 376

(a) The untreated mean and control mean are statistically different. See Appendix D for summary of statistical test results.

(b) The untreated mean and laboratory control mean are not statistically different. See Appendix D for summary of statistical test results.

(c) The laboratory control mean and on-site control mean are statistically different. See Appendix D for summary of statistical test results.

The laboratory turbidities and on-site turbidities for the control samples can be compared directly because whenever a control sample was submitted for laboratory analyses, an on-site turbidity measurement was made at the time that the sample for laboratory analysis was collected. The coefficients of variation for the laboratory turbidity results and on-site turbidity results are 0.6 and 0.1, respectively. The higher coefficient of variation (0.6) for laboratory results may be an indication of the potential differences in storm water quality values that may occur as a result of whether the water quality is assessed immediately on-site, versus days later “off-site” in a commercial laboratory setting. A Student t-Test of the difference between the laboratory turbidity and on-site turbidity means indicates that there is a significant difference ($p < 0.001$) between these two sets of results from the same sample. Possible reasons for this significant difference in the results are discussed following the presentation of the total suspended solids and turbidity results. Additionally, statistical

analyses were performed to assess the significance of the differences between the untreated and control samples means. The independent and paired Student t-Test summary reports are included in Appendix D.

To assist in evaluating the solids removal performance of the coagulants and doses tested, the lower 95 percent confidence interval limits were used as a comparative benchmark as discussed previously. The solids removal achieved in jar tests by aluminum sulfate, ferric chloride, JC 1670, Pass C, Superfloc A1849, and Westchlor 950S are presented in Table 3-4.

Table 3-4. Jar Test Results for Solids Removal

Coagulant and Dose (mg/L)	Trial Number	Temperature (°C)	Sample Date	Total Suspended Solids (mg/L)	Laboratory Turbidity (NTU)	On-site Turbidity (NTU)
Untreated		Mean		232	127	---
Control		Mean		185	124	348
Reporting Limit				1	1	0.5
Aluminum sulfate (Alum)						
5	24	4	12/3/2001	201	74.7	386
20	24	4	12/3/2001	204	70	359
50	24	4	12/3/2001	206	220	365
100	24	4	12/3/2001	67	26.6	80
150	24	4	12/3/2001	77	77.6	75
50	30	15	12/10/2001	201	172	384
100	30	15	12/10/2001	88	97.1	142
Ferric chloride						
5	26	4	12/4/2001	220	80.9	354
20	26	4	12/4/2001	190	88.4	377
50	26	4	12/4/2001	206	100	394
100	26	4	12/4/2001	44	50.9	77
250	26	4	12/4/2001	34	22.2	23
50	30	15	12/10/2001	205	174	363
100	30	15	12/10/2001	115	148	222
JC 1670						
2	22	4	11/28/2001	169	213	302
5	22	4	12/10/2001	183	169	300
20	22	4	11/28/2001	158	163	235
50	22	4	11/28/2001	210	188	317
100	22	4	12/10/2001	200	223	334
5	30	15	11/28/2001	209	163	374
20	30	15	11/28/2001	19	12.2	18

Note: Bolded values are less than or equal to the lower 95 percent confidence limit for the laboratory control samples total suspended solids (169 mg/L), laboratory turbidity (63 NTU), and on-site turbidity (321 NTU) analyses.

Table 3-4. Jar Test Results for Solids Removal

Coagulant and Dose (mg/L)	Trial Number	Temperature (°C)	Sample Date	Total Suspended Solids (mg/L)	Laboratory Turbidity (NTU)	On-site Turbidity (NTU)
Untreated Control		Mean		232	127	---
		Mean		185	124	348
Reporting Limit				1	1	0.5
Pass C						
5	27	4	12/4/2001	188	110	317
20	27	4	12/4/2001	186	74.1	348
50	27	4	12/4/2001	162	65.9	270
100	27	4	12/4/2001	42	2.2	36
250	27	4	12/4/2001	176	100	171
5	28	15	12/4/2001	182	93.8	340
20	28	15	12/4/2001	190	79.1	319
50	28	15	12/4/2001	76	41.3	113
100	28	15	12/4/2001	28	8.9	19
250	28	15	12/4/2001	48	5.9	31
Superfloc A1849						
1	33	4	12/11/2001	132	81.2	194
1.5	31	4	12/11/2001	115	83.3	171
2.5	31	4	12/11/2001	97	68.4	131
3.5	31	4	12/11/2001	85	63.1	117
1.5	32	15	12/11/2001	115	72.1	166
2.5	32	15	12/11/2001	79	57.7	115
Westchlor 950S						
5	31	4	12/11/2001	176	138	316
20	23	4	11/28/2001	215	208	352
20	31	4	12/11/2001	208	134	356
50	23	4	11/28/2001	28	27.6	36
50	31	4	12/11/2001	33	7.6	34
55	23	4	11/28/2001	28	31.2	35
100	23	4	11/28/2001	231	25.3	280
250	23	4	11/28/2001	294	191	424
2	29	15	12/10/2001	197	183	413
5	29	15	12/10/2001	193	183	413
20	29	15	12/10/2001	193	155	426
50	29	15	12/10/2001	21	14.9	23
100	29	15	12/10/2001	135	55	245

Note: Bolded values are less than or equal to the lower 95 percent confidence limit for the laboratory control samples total suspended solids (169 mg/L), laboratory turbidity (63 NTU), and on-site turbidity (321 NTU) analyses.

Two turbidity results are presented in Table 3-4 for each sample. One difference between these two results is that the on-site turbidity measurement occurred at the time of experimentation and the laboratory turbidity measurement (by a state-certified laboratory) was to occur within 48 hours of sample collection. On-site turbidity was measured immediately at the end of each experiment by qualified study personnel using a calibrated turbidimeter meeting the specifications of EPA Method 180.1. According to the analytical

methods for turbidity (EPA Method 180.1) and total suspended solids (EPA Method 160.1), the holding times (i.e., the times between the sample collections and analyses) are “as soon as possible”; however, according to 40CFR Part 136 (NPDES Permit Procedures) the turbidity holding time is 48 hours and total suspended solids holding time is 7 days. The 48-hour turbidity holding time and 7-day total suspended solids holding time were specified in the jar test protocol (see Appendix F). The laboratory understood the QA/QC criteria established for the project. However, the laboratory seldom met the turbidity holding times required by the project. A summary of laboratory compliance with the turbidity holding time requirement is presented in Table 3-5.

Table 3-5. Turbidity Holding Time Summary

Holding Time Status	Number of Samples	Total Percentage (a)	Untreated Samples Percentage (b)	Control Samples Percentage (c)
Holding time met (analyzed within 48 hrs.)	21	24.4%	14.20%	16.7%
Holding time not met (analyzed after 48 hours and samples arrived in time).	26	30.2 %	42.85%	33.3%
Holding time not met (analyzed after 48 hours, but the samples did not arrive in time).	18	21.0 %	---	---
Unknown. The samples were reported to be analyzed on the same date as were collected which was not possible because samples were shipped overnight.	21	24.4 %	42.85%	50.0%
Total	86 samples	100%	100%	100%

(a) Total number of samples submitted to the laboratory for analyses was 86.

(b) Total number of untreated samples submitted to the laboratory for analyses was 7.

(c) Total number of control samples submitted to the laboratory for analyses was 6.

Differences between turbidity results are discussed further, herein, and are significant because 1) turbidity is a regulated water quality parameter, and 2) turbidity is a major criterion used to select the coagulant and dose to be used for field application in the next phase of the study. For the control samples, the laboratory turbidity mean and on-site turbidity mean were 124 NTU and 348 NTU, respectively. The coefficients of variation for the laboratory turbidity data and on-site turbidity data were 0.6 and 0.1, respectively. Clearly, both sets of data cannot be accurate representations of what actually occurred. In so far as all the control samples were obtained from a single batch of storm water the turbidity measurements should be reasonably similar, if the batch of storm water was well preserved and maintained in a homogenous condition throughout the test period. The on-site turbidity results suggest that the batch of storm water was well preserved throughout the test period.

Turbidity in water is caused by the presence of suspended particles such as clay, silt, finely divided organic and inorganic matter, plankton, algae, and other microscopic organisms (AWWA, 1999). Each type of particle has a characteristic light scattering property depending on material composition, size, and shape. One factor that makes gross assessment of turbidity results relatively easy is the ability to visually detect significant differences in

water turbidity without any instrumentation. Very turbid samples are cloudy (high NTU) and less turbid samples are clear (low NTU).

For many aqueous samples there is a relatively predictable, somewhat linear relationship between total suspended solids and turbidity. The relationships between the two turbidity results (on-site and laboratory), and total suspended solids (TSS) results are shown in Figure 3-1 for the data collected using Batch III storm water. As shown, the laboratory turbidity results were lower and more variable than the on-site turbidity results collected at the time of jar testing. The coefficients of determination (R^2) that characterize the “linearity” of the relationships between the turbidity measurements and TSS are also shown. A high R^2 value (e.g., approaching 1.0) indicates a good linear relationship between turbidity and TSS. A low R^2 value indicates a relatively poor linear relationship. Comparing the R^2 values ($R^2 = 0.4$ for laboratory turbidity and $R^2 = 0.9$ for on-site turbidity), one can see that the on-site turbidity results correlate better with the total suspended solids data than do the laboratory turbidity results. The reason(s) for these differences was not investigated beyond verifying with the laboratory that the analytical methods (EPA Method 160.1 and 180.1) were followed.

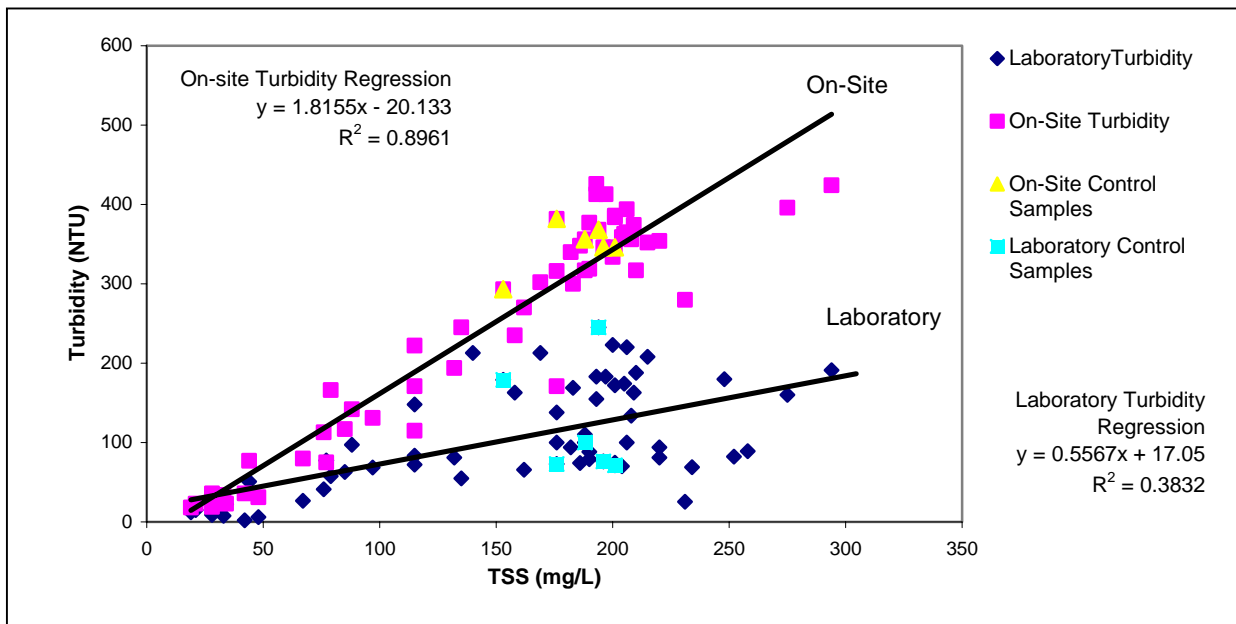


Figure 3-1. Laboratory and On-Site Turbidity in Relation to Total Suspended Solids Results

One might speculate that, as turbidity is an inverse function of particle size for a given total suspended solids concentration, the laboratory results may suggest that flocculation continued until the samples were analyzed. However, the untreated batch of storm water used in these experiments had been stored from days to week prior to actual testing, and yet these periods of extended settling and natural flocculation were easily reversed by mixing of the batch storm water at the time of testing as evidenced by the on-site control sample

turbidity results. On-site turbidity results obtained at the time of jar test coagulant experimentation are plotted against corresponding laboratory control sample turbidity results in Figure 3-2. Although the Figure 3-2 results are for the same sample source, only a weak correlation ($R^2 = 0.35$) between the on-site and laboratory turbidity results is observed.

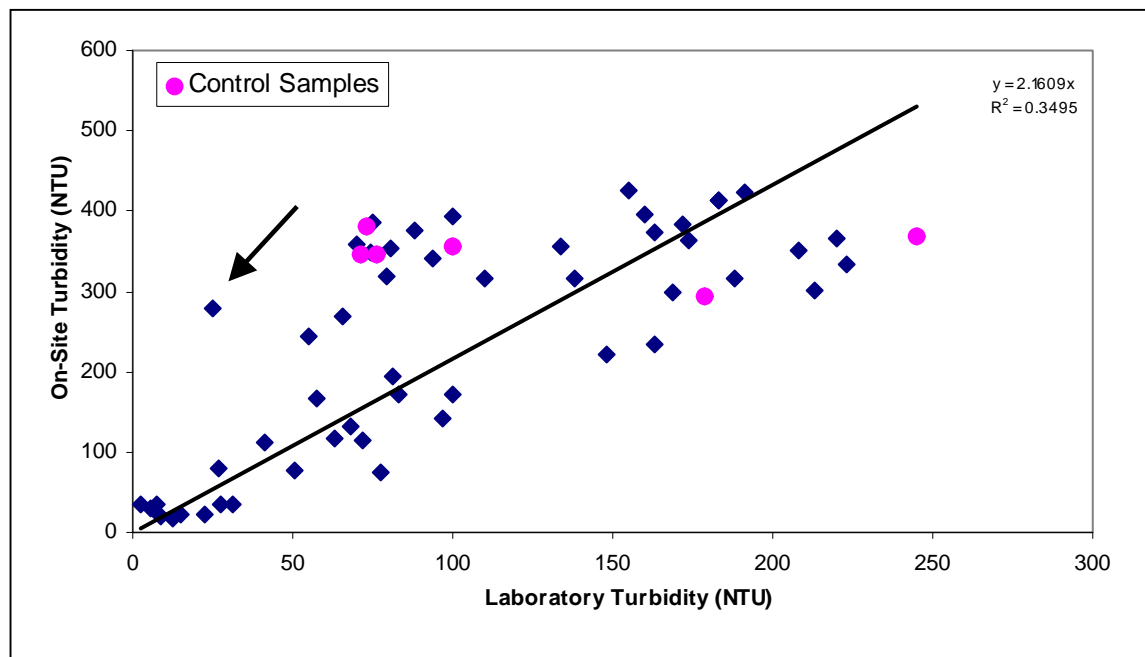


Figure 3-2. Laboratory and On-Site Measurements

Of particular note is the sample identified by the arrow (←), in Figure 3-2 which represents the turbidity results when storm water was dosed with Westchlor 950S at 100 mg/L (4°C). After approximately 30 minutes of sedimentation, the supernatant was removed from the test beaker and distributed into sample containers for further analyses. Following transference of this Westchlor 950S sample into a turbidity vial, the sample continued to settle while queued for on-site turbidity measurement. The settled turbidity sample had a turbidity value similar to that reported by the laboratory (25.3 NTU). Upon agitations of the turbidity vial done in accordance with the analytical method, the turbidity increased to 280 NTU. This turbidity value was commensurate with the cloudy state of the supernatant observed at the time of sample collection when the supernatant was removed from the test beaker. Thus autoflocculation and/or settling of the laboratory samples may have occurred in the samples between the testing site and laboratory, in such a way that resuspension of the settled solids to a representative particle size distribution necessary for representative turbidity analyses may have been difficult. This possibility, in light of the on-site turbidity data and experience, make the representativeness of the laboratory turbidity measurements suspect. The concern over the laboratory turbidity results does not necessarily have implications for the other laboratory results.

All three solids parameters (total suspended solids, laboratory turbidity, and on-site turbidity) results are presented in Table 3-4; however, only the total suspended solids and on-site turbidity results are considered in the evaluations of treatment coagulants because of uncertainty with respect to the representativeness of the lab turbidity measurements. A discussion is presented below evaluating each of the six coagulants solids removal results from the variable temperature jar test experiments. Following the discussions, the six coagulants are ranked based on the doses of each coagulant exhibiting the best solids removal results.

3.2.1 Aluminum Sulfate (Alum) Treatment

The total suspended solids concentrations and on-site turbidity data (see Table 3-4) indicate that the best solids removal occurred when aluminum sulfate was dosed at 100 mg/L (4°C), which was the dose selected for 1) further study (in the phosphate-spiked experiments), and 2) comparative evaluation. Aluminum sulfate doses greater than 5.0 mg/L required the use of NaOH for pH adjustment (as will be discussed when the aluminum data are presented).

3.2.2 Ferric Chloride Treatment

Total suspended solids concentrations were not reduced until the ferric chloride coagulant dose was at least 100 mg/L (4°C and 15°C). The best total suspended solids and turbidity removals occurred at the ferric chloride dose of 250 mg/L (4°C). Ferric chloride doses greater than 20 mg/L required the use of NaOH to maintain pH between 6.0 and 7.0 (as will be discussed when the aluminum data are presented). The 250 mg/L ferric chloride dose is not recommended due to the large amount of sludge produced, and the large amount of NaOH needed to maintain pH after coagulant addition. Ferric chloride dosed at 100 mg/L reduced total suspended solids and turbidity substantially, though not quite as well as at 250 mg/L. Based on the relatively minor gain in solids removal for significantly greater coagulant dose (and associated NaOH usage and sludge production), a ferric chloride dose of 100 mg/L was the chosen dose over the 250 mg/L dose for 1) further study (in the phosphate-spiked experiments), and 2) comparative evaluation.

3.2.3 JC 1670 Treatment

JC 1670 was most effective at removing total suspended solids and turbidity at a dose of 20 mg/L at both 15°C and 4°C. However, the amount of solids removed by JC 1670 decreased substantially with decreased water temperature (see Table 3-4). Temperature appears to have a significant impact on the effectiveness of this coagulant. JC 1670 did not appear to consume alkalinity at the doses tested, i.e., no NaOH addition was necessary to maintain pH in the 6 to 7 range. The JC 1670 dose selected for 1) further study and 2) comparative evaluation was 20 mg/L based on turbidity and total suspended solids removal results.

3.2.4 Pass C Treatment

Pass C was most effective at removing total suspended solids and turbidity at a dose of 100 mg/L at both temperatures tested. At 4°C, though, increasing the Pass C dose to 250 mg/L caused the total suspended solids and turbidity to increase substantially, i.e., higher doses caused poorer performance. At 15°C, the loss in solids removal performance caused by increasing Pass C dosage beyond 100 mg/L was decreased. This suggests that temperature, particularly colder temperature, affects the performance of this coagulant, at least at higher doses. Pass C appeared to consume alkalinity (supernatant alkalinity concentrations dropped) with increasing coagulant dose, although not to a degree that NaOH additions were necessary. The Pass C dose of 100 mg/L was selected for 1) further study (in the phosphate-spiked experiments), and 2) comparative evaluation.

3.2.5 Superfloc A1849 Treatment

For Superfloc A1849, total suspended solids concentrations and turbidity declined with increasing doses up to the maximum dose studied of 3.5 mg/L. Superfloc A1849 did not show a significant effect on alkalinity. The 3.5 mg/L dose was not selected for further study and comparative evaluation because of the relative toxicity of this compound (NSF recommends a maximum dose of 3.5 mg/L). To reduce the possibility for toxicity problems occurring as a result of dosing errors in a field application, Superfloc A1849 dosed at 2.5 mg/L was the dose selected for 1) further study and 2) comparative evaluation.

3.2.6 Westchlor 950S Treatment

For Westchlor 950S, reductions in total suspended solid concentrations and turbidity were greatest at a dose of about 50 mg/L. At higher doses, both total suspended solids and turbidity removal performance decreased substantially. Alkalinity also decreased as Westchlor 950S doses increased. The Westchlor 950S dose selected for further study and for comparative evaluation was 50 mg/L.

3.2.7 Solids Summary

The solids removal performance of the coagulants tested is considered most important for storm water treatment because high suspended solids and turbidities are frequently associated with high concentrations of other pollutants that are either particulate in nature or dissolved/colloidal but adsorbed to larger particulates. Turbidity results for coagulant treatments are summarized and ranked at 4°C and 15°C in Tables 3-6 and 3-7, respectively. The suspended solids results were not included in these summaries because turbidity and suspended solids are both measures of unsettled particulate matter, and turbidity is the parameter of interest to Lake Tahoe Basin regulators (Regional Board).

Coagulant treatments resulting in the lowest turbidities and suspended solids concentrations are considered best. A ranking value of “one” corresponded to the lowest turbidity result. In

this regard, based on the turbidity results presented in Tables 3-6 and 3-7, Pass C and Westchlor 950S are the best coagulants at lower water temperatures; and Pass C, Westchlor 950S, and JC 1670 are the best coagulants at higher water temperatures. The dose for each coagulant causing the best solids reduction (see doses summarized in Tables 3-6 and 3-7) are those that were used for comparison throughout the remainder of the analyses.

Table 3-6. Turbidity Relative Rankings: 4°C

Coagulant	Best Dose (mg/L)	On-site Turbidity (NTU)	Turbidity Rank
Aluminum Sulfate	100	80	4
Ferric Chloride	100	77	3
JC 1670	20	235	6
Pass C	100	36	2
Superfloc A1849	2.5	131	5
Westchlor 950S	50	23	1

Note: Bolded values are less than or equal to the lower 95 percent confidence limit (321 NTU) for the combined 4°C and 15°C control samples on-site turbidity mean (348 NTU).

Table 3-7. Turbidity Relative Rankings: 15°C

Coagulant	Best Dose (mg/L)	On-site Turbidity (NTU)	Turbidity Rank
Aluminum Sulfate	100	142	5
Ferric Chloride	100	222	6
JC 1670	20	18	1
Pass C	100	19	2
Superfloc A1849	2.5	115	4
Westchlor 950S	50	23	3

Note: Bolded values are less than or equal to the lower 95 percent confidence limit (321 NTU) for the combined 4°C and 15°C control samples on-site turbidity mean (348 NTU).

3.3 Nutrients

The nutrient group of monitored parameters includes total and filtered ammonia, nitrate, nitrite, filtered and total Kjeldahl nitrogen (TKN), filtered and total orthophosphate, and filtered and total phosphorous. Iron is also considered an important micronutrient with regard to algae growth in Lake Tahoe. Though iron is of concern in Lake Tahoe from a nutrient perspective, iron is discussed with metals, not nutrients, because of its primarily inorganic sources.

The objectives of the nutrient analyses were 1) to determine the concentrations and relative proportions of dissolved nutrients versus particulate nutrients in Lake Tahoe Basin roadway runoff storm water, and 2) to assess how the coagulants changed these concentrations and proportions. The untreated and control analytical data indicated that many of the nutrient concentrations in Lake Tahoe Basin roadway storm water were low to non-detect,

particularly ammonia, nitrate, nitrite, and phosphate concentrations (Appendices B and D). Consequently, 1) treatment of these contaminants could not be “real-time” tested, and 2) treatment may not be necessary if continued Caltrans monitoring of roadway storm water quality provides further insight into sources and timing of roadway storm water pollutant releases such that the Regional Board grants effluent limitations with averaging periods.

Untreated and control sample results for the nitrogen species are shown in Tables 3-8 and 3-9. The Caltrans DAT program requires that at least three samples have detectible concentrations and that a total of 20 percent of all the samples have detectible concentrations. Nitrate and nitrite were never present at concentrations above their respective reporting limits. Total Kjeldahl nitrogen (TKN) includes all reduced forms of nitrogen (i.e., ammonia and organic nitrogen) and was always present in concentrations above reporting limits. Ammonia concentrations were often below the reporting limits (only 2 of the 7-untreated samples contained detectible levels of ammonia). The consistent presence of TKN, the relative lack of ammonia, and the total lack of oxidized nitrogen species indicate that almost all nitrogen in the storm water collected for this study was in the reduced, organic form at the time of analysis.

Table 3-8. Nitrogen Results for Untreated and Control Samples: Means (a)

Sample	Ammonia, Total (mg/L as N)	Ammonia, Filtered (mg/L as N)	Nitrate (mg/L as N)	Nitrite (mg/L as N)	TKN, Total (mg/L as N) (b)	TKN, Filtered (mg/L as N) (b)
Untreated	29% detected	14% detected	0% detected	0% detected	1.53	1.16
Control	0.13	0% detected	0% detected	0% detected	1.63	0.95
Reporting limits	0.10	0.10	0.10	0.10	0.10	0.10

(a) A mean value was calculated only if at least of the 3 of 7-untreated sample results (43 percent) and at least 3 of the 6-control sample results (50 percent) were detectible.

(b) The untreated and control sample means are not statistically different from each other. See Appendix D for summary of statistical test results.

Table 3-9. Nitrogen Results for Untreated and Control Samples: 95 Percent Confidence Interval Limits (a)

Sample	Ammonia, Total (mg/L as N)	Ammonia, Filtered (mg/L as N)	Nitrate (mg/L as N)	Nitrite (mg/L as N)	TKN (mg/L as N)	TKN, Filtered (mg/L as N)
Untreated	29% detected	14% detected	0% detected	0% detected	1.11 to 1.95	0.92 to 1.40
Control	0.10 to 0.16	0% detected	0% detected	0% detected	1.20 to 2.06	0.63 to 1.28
Reporting limits	0.10	0.10	0.10	0.10	0.10	0.10

(a) Confidence interval limit was calculated only if at least of the 3 of the 7-untreated sample results (43 percent) and at least 3 of the 6-control sample results (50 percent) were detectible.

Untreated and control sample results for phosphorous species analyzed are presented in Tables 3-10 and 3-11. Neither total nor filtered orthophosphate was present at concentrations above reporting limits in the storm water used for this study. Total phosphorous in forms other than orthophosphate were always present at concentrations above reporting limits.

Filtered phosphorous was always near or below the reporting limit; thus eliminating the ability to evaluate the relative effectiveness of the coagulants at reducing filtered phosphorous concentrations. Since phosphate removal is a key concern in the Lake Tahoe Basin, subsequent jar tests using samples spiked with phosphate were conducted as discussed in Section 4 of this report.

Table 3-10. Phosphorous Results for Untreated and Control Samples: Means (a)

Sample	Ortho Phosphate, Total (mg/L as P)	Ortho Phosphate, Filtered (mg/L as P)	Phosphorous, Total (mg/L as P) (b)	Phosphorous, Filtered (mg/L as P) (c)
Untreated	0% detected	0% detected	0.46	0.07
Control	0% detected	0% detected	0.36	0.08
Reporting limit	0.03	0.03	0.03	0.03

(a) A mean value was calculated only if at least of the 3 of 7-untreated sample results (43 percent) and at least 3 of the 6-control sample results (50 percent) were detectable.

(b) The untreated and control means are statistically different. See Appendix D for summary of statistical test results.

(c) The untreated and control means are not statistically different. See Appendix D for summary of statistical test results.

Table 3-11. Phosphorous Results for Untreated and Control Samples: 95 Percent Confidence Limits (a)

Sample	Ortho Phosphate, Total (mg/L as P)	Ortho Phosphate, Filtered (mg/L as P)	Phosphorous, Total (mg/L as P)	Phosphorous, Filtered (mg/L as P)
Untreated	0% detected	0% detected	0.39 to 0.54	0.01 to 0.14
Control	0% detected	0% detected	0.32 to 0.41	0.05 to 0.10
Reporting limit	0.03	0.03	0.03	0.03

(a): Confidence interval limits values were calculated only if at least of the 3 of 7-untreated sample results (43 percent) and at least 3 of the 6-control sample results (50 percent) were detectable.

All of the nutrient results for the various coagulant treatment jar tests are shown in Table 3-12. The performance of each of the coagulants tested to reduce total and filtered TKN and phosphorous is discussed below.

3.3.1 Aluminum Sulfate (Alum) Treatment

Total and filtered TKN concentrations were reduced substantially by aluminum sulfate doses of 50 mg/L and 100 mg/L at 15°C. Reductions to a lesser degree occurred in the 4°C jar tests. In fact, the filtered TKN concentrations hardly changed in the 4°C tests. As noted in the earlier discussion of the total suspended solids and turbidity data, cold temperatures may adversely affect the treatment performance of this coagulant. Aluminum sulfate is known to be sensitive to colder temperatures (AWWA, 1999).

Total phosphorous and filtered phosphorous concentrations were reduced substantially by aluminum sulfate doses of 100 mg/L and 150 mg/L at 4°C. The same reductions of total and filtered phosphorous concentrations were not observed at 15°C for the same 100 mg/L dose of aluminum sulfate. Reasons for the reductions of filtered phosphorous (but not total phosphorous) when lower aluminum sulfate doses were tested (5 mg/L or 20 mg/L) at 4°C

remain unknown. In terms of phosphorous removal, the performance of aluminum sulfate apparently increased at lower temperatures. Aluminum sulfate coagulation is a recognized treatment option to remove phosphorous from water, whether the variability in response is 1) related to phosphorous-coagulant interactions (as compared to TKN removal), or 2) an artifact of variability, is unknown.

3.3.2 Ferric Chloride Treatment

Total and filtered TKN concentrations were reduced substantially by the ferric chloride dose of 100 mg/L at 15°C. Reductions to a lesser degree occurred when ferric chloride was dosed at concentrations up to 250 mg/L at 4°C. The reductions in the concentrations of TKN generally were increased with increased dose concentrations at 4°C. The 250 mg/L dose most reduced TKN concentrations. At 15°C, total and filtered TKN concentrations were reduced most at the 100 mg/L dose. The results suggest that TKN removal performance by ferric chloride may be enhanced by increasing water temperature in the 4°C to 15°C range. Insufficient information is available at this time to suggest reasons for such an effect.

Reductions in total phosphorous concentrations in the 4°C trials generally increased as the ferric chloride dose increased with one exception (5 mg/L dose). Filtered phosphorus concentrations did not appear to vary significantly with coagulant dose during the 4°C trials. The total and filtered phosphorous concentrations that were reduced substantially by the 5 mg/L ferric chloride dose tested at 4°C remain unexplained. At 15°C, this coagulant was apparently ineffective at removing total and filtered phosphorus, possibly suggesting a temperature effect. The optimum ferric chloride doses to reduce phosphorous concentrations based on these results are 100 mg/L and 250 mg/L.

3.3.3 JC 1670 Treatment

Total TKN concentrations were substantially reduced at 15°C with JC 1670 dosed at both 5 mg/L and 20 mg/L (with the 20 mg/L dose producing somewhat lower total TKN concentrations). Filtered TKN was substantially reduced by a JC 1670 20 mg/L dose, but not by a 5 mg/L dose at 15°C. Generally speaking, JC 1670 was not effective at removing TKN at 4°C. The TKN concentrations were reduced as the JC 1670 dose increased until the optimum dose (20 mg/L) was reached and then TKN concentrations increased with increasing dose, suggesting an overdosing phenomenon.

Total phosphorous concentrations were reduced substantially when JC 1670 was dosed at 20 and 100 mg/L at 4°C and 20 mg/L at 15°C. Filtered phosphorous concentrations were at or below the reporting limit for doses of 50 and 100 mg/L tested at 4°C. Similar reductions were not seen at 15°C.

Table 3-12. Nutrient Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (° C)	Sample Date	Ammonia, Total as N (mg/L)	Ammonia, Filtered as N (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	TKN (mg/L)	TKN,Filtered (mg/L)	Ortho-Phosphate, Total as P (mg/L)	Ortho-Phosphate Filtered as P (mg/L)	Phosphorous, Total as P (mg/L)	Phosphorous, Filtered as P (mg/L)
Untreated	Mean	Varies	Varies	Insufficient detections	Insufficient detections	Insufficient detections	Insufficient detections	1.53	1.16	Insufficient detections	Insufficient detections	0.46	0.07
Control	Mean	Varies	Varies	0.13	Insufficient detections	Insufficient detections	Insufficient detections	1.63	0.95	Insufficient detections	Insufficient detections	0.36	0.08
Control	Lower 95% Confidence Interval Limit			0.10	---	---	---	1.20	0.63	---	---	0.32	0.05
Reporting Limit				0.10	0.10	0.10	0.10	0.10	0.10	0.03	0.03	0.03	0.03
Aluminum Sulfate (Alum)													
5	24	4	12/3/2001	0.15	ND	ND	ND	2.01	1.06	ND	ND	0.46	0.04
20	24	4	12/3/2001	ND	ND	ND	ND	2.22	1.15	ND	ND	0.45	0.03
50	24	4	12/3/2001	ND	ND	ND	ND	1.24	0.96	ND	ND	0.46	0.08
100	24	4	12/3/2001	0.13	ND	ND	ND	2.54	0.93	ND	ND	0.14	0.03
150	24	4	12/3/2001	0.18	ND	ND	ND	0.99	0.83	ND	ND	0.11	0.03
50	30	15	12/10/2001	0.10	ND	ND	ND	0.33	0.30	ND	ND	0.58	0.24
100	30	15	12/10/2001	ND	ND	ND	ND	0.40	0.33	ND	ND	0.38	0.23
Ferric Chloride													
5	26	4	12/4/2001	0.10	ND	ND	ND	1.32	1.26	ND	ND	0.04	0.04
20	26	4	12/4/2001	ND	ND	ND	ND	1.68	1.07	ND	ND	0.38	0.03
50	26	4	12/4/2001	ND	ND	ND	ND	1.49	1.00	ND	ND	0.37	0.04
100	26	4	12/4/2001	ND	ND	ND	ND	1.27	0.81	ND	ND	0.10	0.06
250	26	4	12/4/2001	ND	ND	ND	ND	0.73	0.64	ND	ND	0.06	0.03
50	30	15	12/10/2001	0.17	0.12	ND	ND	1.23	0.96	ND	ND	0.50	0.24
100	30	15	12/10/2001	0.18	0.11	ND	ND	0.43	0.39	ND	ND	0.44	0.23
JC 1670													
2	22	4	11/28/2001	0.12	ND	ND	ND	2.73	2.16	ND	ND	0.40	0.05
5	22	4	11/28/2001	0.10	ND	ND	ND	2.32	1.25	ND	ND	0.35	0.04
20	22	4	11/28/2001	ND	ND	ND	ND	1.87	1.28	ND	ND	0.30	0.03
50	22	4	11/28/2001	0.12	ND	ND	ND	2.02	1.84	ND	ND	0.36	ND
100	22	4	11/28/2001	0.10	ND	ND	ND	2.78	2.09	ND	ND	0.28	ND
5	30	15	12/10/2001	0.22	0.17	ND	ND	1.05	0.80	ND	ND	0.52	0.17
20	30	15	12/10/2001	0.29	0.21	ND	ND	0.72	0.55	ND	ND	0.22	0.19

Note: Bolded values are less than or equal to the lower 95% confidence limit for the control samples.

Table 3-12. Nutrient Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (° C)	Sample Date	Ammonia, Total as N (mg/L)	Ammonia, Filtered as N (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	TKN (mg/L)	TKN,Filtered (mg/L)	Ortho-Phosphate, Total as P (mg/L)	Ortho-Phosphate Filtered as P (mg/L)	Phosphorous, Total as P (mg/L)	Phosphorous, Filtered as P (mg/L)
Untreated	Mean	Varies	Varies	Insufficient detections	Insufficient detections	Insufficient detections	Insufficient detections	1.53	1.16	Insufficient detections	Insufficient detections	0.46	0.07
Control	Mean	Varies	Varies	0.13	Insufficient detections	Insufficient detections	Insufficient detections	1.63	0.95	Insufficient detections	Insufficient detections	0.36	0.08
Control	Lower 95% Confidence Interval Limit			0.10	---	---	---	1.20	0.63	---	---	0.32	0.05
Reporting Limit				0.10	0.10	0.10	0.10	0.10	0.10	0.03	0.03	0.03	0.03
Pass C													
5	27	4	12/4/2001	ND	ND	ND	ND	1.92	0.98	ND	ND	0.35	0.04
20	27	4	12/4/2001	ND	ND	ND	ND	1.95	1.27	ND	ND	0.38	0.03
50	27	4	12/4/2001	0.11	ND	ND	ND	4.45	0.94	ND	ND	0.35	0.03
100	27	4	12/4/2001	0.13	ND	ND	ND	0.89	0.88	ND	ND	0.09	ND
250	27	4	12/4/2001	0.16	0.11	ND	ND	1.62	0.77	ND	ND	0.25	ND
5	28	15	12/4/2001	0.16	ND	ND	ND	1.15	1.08	ND	ND	0.39	0.03
20	28	15	12/4/2001	0.12	ND	ND	ND	1.14	1.05	ND	ND	0.37	ND
50	28	15	12/4/2001	0.14	ND	ND	ND	1.26	1.07	ND	ND	0.18	ND
100	28	15	12/4/2001	0.20	ND	ND	ND	0.80	0.48	ND	ND	0.05	0.05
250	28	15	12/4/2001	ND	ND	ND	ND	1.23	0.51	ND	ND	0.12	0.03
Superfloc A 1849													
1	33	4	12/11/2001	0.17	0.13	ND	ND	1.81	0.21	ND	ND	0.30	0.05
1.5	31	4	12/11/2001	0.26	0.18	ND	ND	2.44	2.05	ND	ND	0.24	0.04
2.5	31	4	12/11/2001	0.23	0.22	ND	ND	1.93	1.89	ND	ND	0.19	ND
3.5	31	4	12/11/2001	0.32	0.2	ND	ND	2.53	2.20	ND	ND	0.21	0.05
1.5	32	15	12/11/2001	0.23	0.16	ND	ND	2.52	1.87	ND	ND	0.28	0.05
2.5	32	15	12/11/2001	0.25	0.17	ND	ND	1.76	0.23	ND	ND	0.18	0.05
Westchlor 950S													
5	31	4	12/11/2001	0.28	0.19	ND	ND	2.89	2.41	ND	ND	0.42	0.04
20	23	4	11/28/2001	ND	ND	ND	ND	1.10	0.85	ND	ND	0.45	ND
20	31	4	12/11/2001	0.27	0.20	ND	ND	2.45	1.40	ND	ND	0.42	0.04
50	23	4	11/28/2001	ND	ND	ND	ND	1.17	0.77	ND	ND	0.07	ND
50	31	4	12/11/2001	0.24	0.23	ND	ND	2.11	1.72	ND	ND	0.09	0.03
55	23	4	11/28/2001	ND	ND	ND	ND	2.53	1.20	ND	ND	0.07	ND
100	23	4	11/28/2001	0.10	ND	ND	ND	3.13	1.13	ND	ND	0.40	ND
249	23	4	11/28/2001	ND	ND	ND	ND	1.60	1.39	ND	ND	0.49	0.03
2	29	15	12/10/2001	0.21	0.17	ND	ND	0.36	0.14	ND	ND	0.61	0.22
5	29	15	12/10/2001	ND	ND	ND	ND	0.17	0.13	ND	ND	0.57	0.20
20	29	15	12/10/2001	ND	ND	ND	ND	1.71	1.35	ND	ND	0.59	0.19
50	29	15	12/10/2001	0.18	0.14	ND	ND	1.18	1.17	ND	ND	0.33	0.22
100	29	15	12/10/2001	0.28	0.20	ND	ND	1.08	0.61	ND	ND	0.36	0.17

Note: Bolded values are less than or equal to the lower 95% confidence limit for the control samples.

3.3.4 Pass C Treatment

The greatest reduction in total TKN occurred with Pass C doses of 100 mg/L at both 4°C and 15°C. A high total TKN concentration (4.45 mg/L) was reported in the sample from the jar test conducted at 4°C and dosed with 50 mg/L Pass C, and was greater than the upper 95 percent confidence interval limit for either the untreated (1.92 mg/L) or the control (2.06 mg/L) samples, suggesting that this high TKN result may be anomalous. Reductions in filtered TKN resulting from a Pass C dose of 100 mg/L were minor at 4°C and substantial at 15°C.

Reductions in total phosphorous concentrations were greatest with Pass C doses of 100 mg/L and 250 mg/L at 4°C, and at 50 mg/L, 100 mg/L, and 250 mg/L at 15°C. Filtered phosphorous concentrations were near or below the reporting limit for all Pass C doses (5 mg/L to 250 mg/L) at both temperatures. Overall, the best results were observed when the coagulant was dosed at 100 mg/L.

3.3.5 Superfloc A1849 Treatment

Generally, this coagulant was not effective at removing total TKN at either temperature tested. There were reductions in the concentrations of filtered TKN at doses of 1.0 mg/L at 4°C, and at 2.5 mg/L at 15°C; however, these data may be anomalous when viewed as part of the overall pattern of results. The best total phosphorous reductions occurred at a dose of 2.5 mg/L at both 4°C and 15 °C.

3.3.6 Westchlor 950S Treatment

Significant reductions in the concentrations of total and filtered TKN were reported when Westchlor 950S was dosed at 2 mg/L and 5 mg/L in the 15°C tests. These reductions did not occur at 4°C, though the 20 mg/L dose showed some reduction at 4°C. In the cases of the 20 mg/L and 50 mg/L doses at 4°C, conflicting results were obtained with repeated tests, one showing possible minor removal and the other not, possibly reflecting the variability of the storm water tested, or other factors inherent to the testing and/or analytical procedures used. For summaries of these data, average values of the 50 mg/L dose were used unless indicated otherwise.

Significant reductions in total phosphorous concentrations were observed only when Westchlor 950S was dosed at (or about) 50 mg/L at 4°C. Only a modest reduction was observed in total phosphorous at this dose at 15°C. Filtered phosphorous concentrations were reduced for all doses at 4°C; and were not reduced with any dose at 15°C, possibly indicating temperature effects.

3.3.7 Nutrient Summary

Total TKN and phosphorous results for the selected optimum coagulant doses at 4°C and 15°C are presented and ranked in Tables 3-13 and 3-14. A ranking value of “one” corresponded to the lowest TKN concentration and the lowest total phosphorous concentration. The selected optimum coagulant doses were chosen primarily for their effectiveness at removing turbidity. These data indicate that the optimum doses to remove turbidity also produced some of the best nutrient removal results. The coagulant judged to produce the best overall nutrient removal results is Pass C at 100 mg/L.

Table 3-13. Nutrient Summary and Relative Rankings: 4°C

Coagulant	Dose (mg/L)	TKN, Total as N (mg/L)	TKN Rank	Phosphorous, Total as P (mg/L)	Phosphorous Rank	Ranking Sum	Overall 4° Rank
Aluminum Sulfate	100	2.54	6	0.14	4	10	4
Ferric Chloride	100	1.27	2	0.10	3	5	3
JC 1670	20	1.87	4	0.30	6	10	4
Pass C	100	0.89	1	0.09	2	3	1
Superfloc A1849	2.5	1.93	5	0.19	5	10	4
Westchlor 950S	50	1.64*	3	0.08*	1	4	2

Notes: *Average of two tests using Westchlor 950 dose of 50 mg/L.

Bolded values are less than or equal to the lower 95 percent confidence limit for the control samples (i.e., 1.2 mg/L TKN and 0.32 mg/L total phosphorous).

Table 3-14 Nutrient Summary and Relative Rankings: 15°C

Coagulant	Dose (mg/L)	TKN, Total as N (mg/L)	TKN Rank	Phosphorous, Total as P (mg/L)	Phosphorous Rank	Ranking Sum	Overall 15° Rank
Aluminum Sulfate	100	0.40	1	0.38	5	6	2
Ferric Chloride	100	0.43	2	0.44	6	8	4
JC 1670	20	0.72	3	0.22	3	6	2
Pass C	100	0.80	4	0.05	1	5	1
Superfloc A1849	2.5	1.76	6	0.18	2	8	4
Westchlor 950S	50	1.18	5	0.33	4	9	6

Note: Bolded values are less than or equal to the lower 95 percent confidence limit for the control samples (i.e., 1.2 mg/L TKN and 0.32 mg/L total phosphorous).

3.4 Metals

Analyses were performed to evaluate the ability of the tested coagulants to remove metals from storm water, specifically iron, which is a regulated storm water pollutant. The Regional Board total iron limit for discharges of storm water to surface waters in the Lake Tahoe Basin is 0.5 mg/L (total iron).

The Regional Board does not directly regulate metals other than iron in storm water discharges at this time. However, there are references in the Caltrans NPDES Storm Water Permit to water quality objectives necessary to maintain the beneficial uses of surface waters receiving storm water; and, aquatic life criteria have been developed for many metals including common motor vehicle metals such as chromium, copper, lead, and zinc. Consequently, these metals were monitored during the Jar Testing Study.

As stated previously, aquatic toxicity caused by some metals is influenced by hardness (e.g., as hardness increases, metal toxicity decreases, and vice versa). The chronic and acute aquatic criteria for the metals analyzed in this study (which are hardness dependent) are summarized in Table 3-15. These criteria are based on a hardness of 25 mg/L as CaCO₃, the lowest storm water hardness concentration reported for the untreated and control samples tested during this study. The chronic criteria are four-day averaged concentrations and the acute criteria are maximum short-term concentrations. The criteria presented in Table 3-15 were developed using methodology outlined by the USEPA as promulgated in the California Toxics Rule (EPA, 2000).

Table 3-15. CTR Metals Criteria

Metal		CTR Criteria (a)	
		Chronic (µg/L)	Acute (µg/L)
Chromium (III)	Total	66	570
	Filtered (b)	57	180
Copper	Total	2.8	3.8
	Filtered (b)	2.7	3.6
Lead	Total	0.54	14
	Filtered (b)	0.54	14
Zinc	Total	37	37
	Filtered (b)	36	36

(a) California Toxics Rule (CTR) criteria are based on a hardness concentration of 25 mg/L as CaCO₃.

(b) Filtered metals are defined as those passing through a 0.45 µm filter; therefore, the filtered criteria indicated are also termed the dissolved criteria.

Total and filtered metal concentrations reported in the untreated samples and control samples were compared to characterize the distribution of metal data and possible sedimentation

treatment effects (untreated without sedimentation versus control with sedimentation). The results of this comparison are presented in Figures 3-3, 3-4, 3-5, 3-6, and 3-7.

The total metal concentrations for chromium, copper, lead, zinc, and iron from six paired untreated and control samples (plus one additional untreated sample) are shown in Figure 3-3, 3-5, and 3-7. Sedimentation is expected to reduce particulate pollutant concentrations; and therefore, total metals concentrations in the control samples would be expected to be lower than in the untreated samples. However, the results illustrate that a reduction occurred in only four of six paired jar tests, in general. Also, the paired data generally do not vary as much as compared to the variability within datasets. A reasonable conclusion from the limited available data is that most of the metals tested in these storm water samples were not associated with particles that will settle within 30 minutes.

Sedimentation effects on filtered metals (i.e., dissolved metals) were not expected and were not observed except for some notable anomalies particularly in the copper results. The expectation that dissolved metals would be unaffected by 30 minutes of sedimentation is based on the understanding that dissolved metals are those metals in solution or adsorbed to colloidal particles with diameters less than 0.45 μm that would remain suspended in solutions for well in excess of 30 minutes. Yet in the case of copper, the dissolved copper concentrations significantly increased in four of the six trials as a result of sedimentation. The possibility was considered that a “pre-coating” phenomenon, more evident with the untreated sample than the control sample (that had undergone sedimentation), could contribute to these apparent “counter-intuitive” results. Pre-coating occurs by fine particles (only slightly larger than 0.45 μm) that are trapped and accumulate at the filter interface, thereby decreasing the effective pore size of the filter media. If this were the case, the untreated samples would have higher fractions of particles slightly larger than the control samples allowing for the untreated samples to be “better filtered” than the control samples, and hence a decreased dissolved metal concentration in the untreated samples. As this “sedimentation effect” was most noticeable for copper, insufficient information is available to fully explain these results, particularly since disposable filters were used and very small volumes of storm water were filtered, i.e., “pre-coat” phenomenon should not have occurred.

The statistical analyses of means using reported data for paired untreated and control samples did not conclude that there were statistical differences between any of the untreated and control means (see paired t-tests, Appendix D). Therefore, any difference between the two datasets possibly due to sedimentation was not demonstrated by these jar test experimental results. Summaries of the reported untreated and control samples detections, means, and 95 percent confidence limits (Appendix D), are presented in Tables 3-16 and 3-17 for the total and filtered metals results, respectively. The metal removal results for the jar tests dosed with aluminum sulfate, ferric chloride, Superfloc A1849, Pass C, JC 1670, or Westchlor 950S are presented in Table 3-18, and are discussed in the sections that follow.

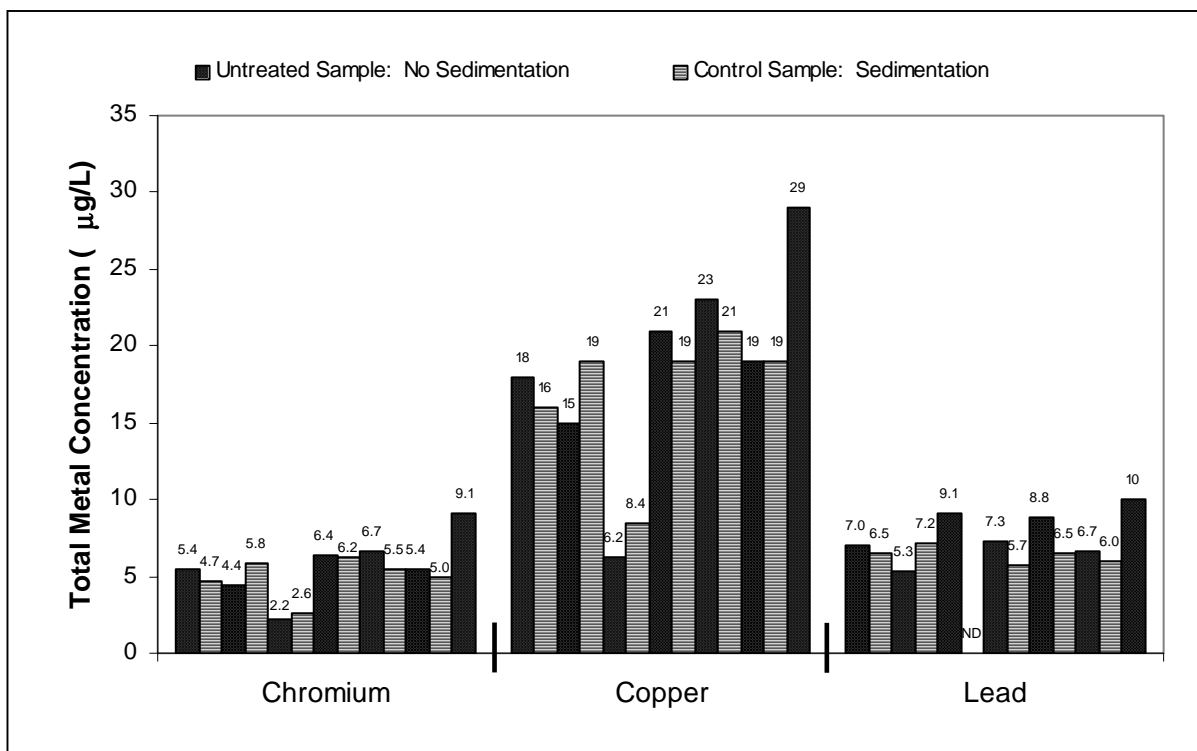


Figure 3-3. Total Metal Concentrations

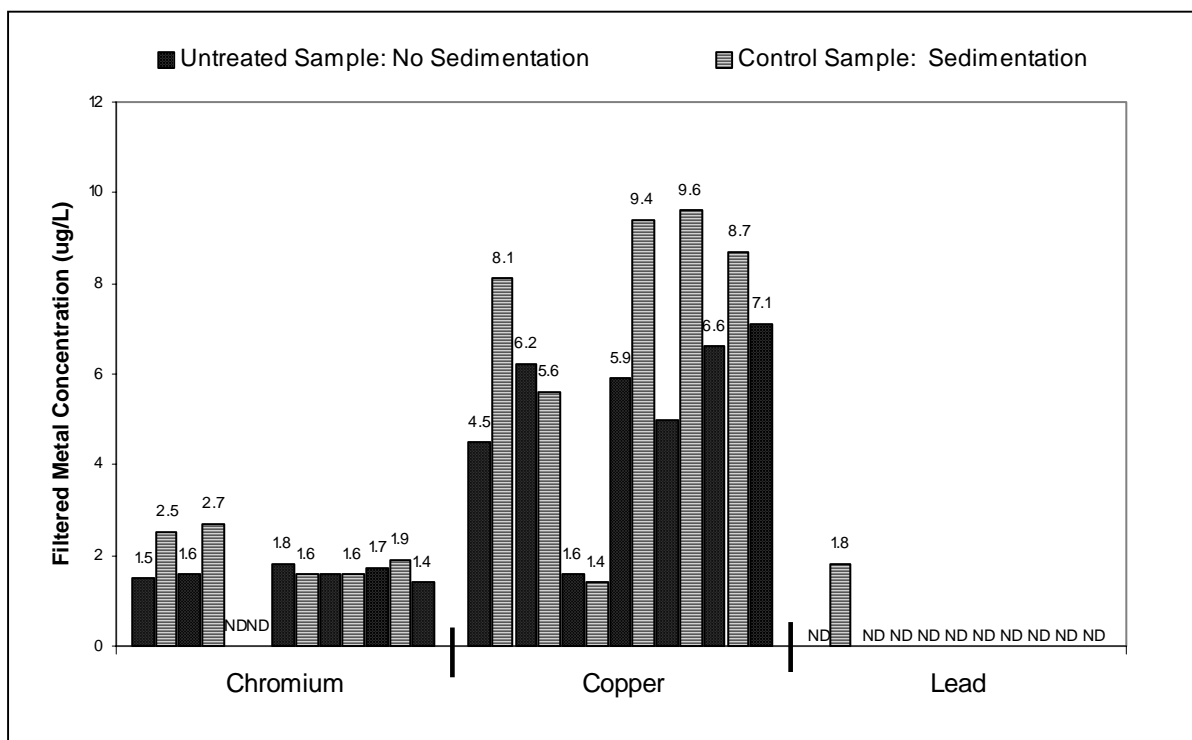


Figure 3-4. Filtered Metal Concentrations

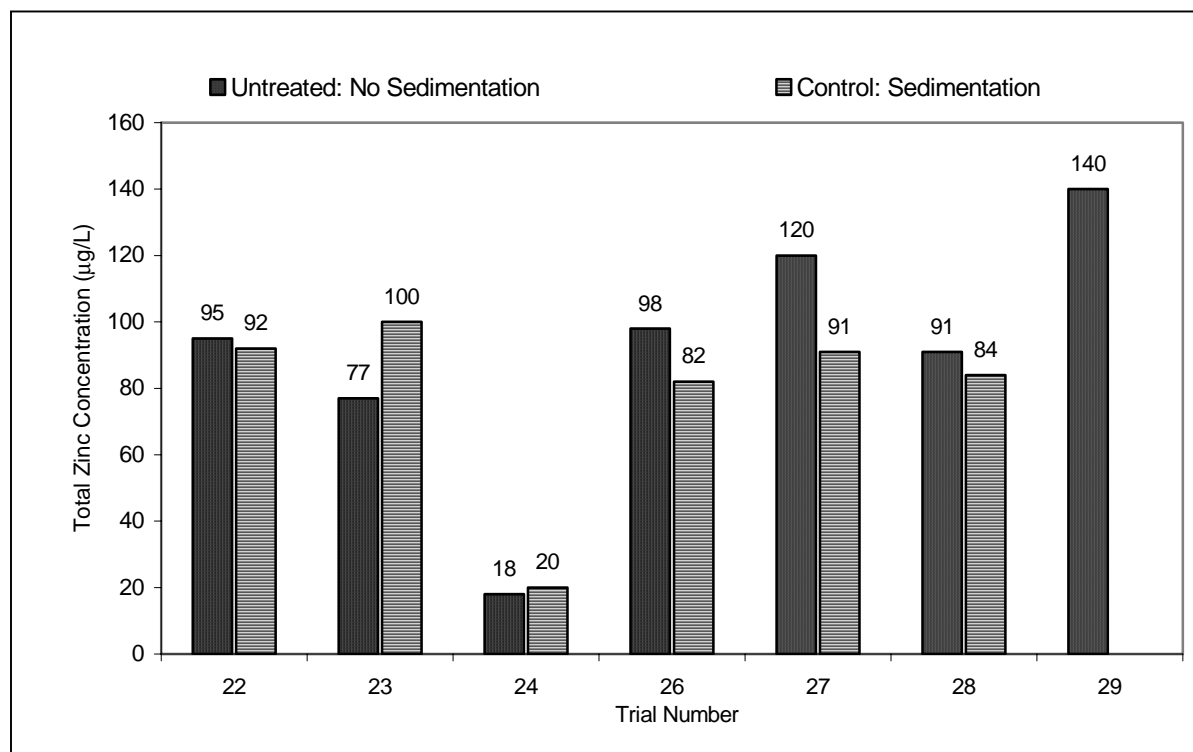


Figure 3-5. Total Zinc Concentrations

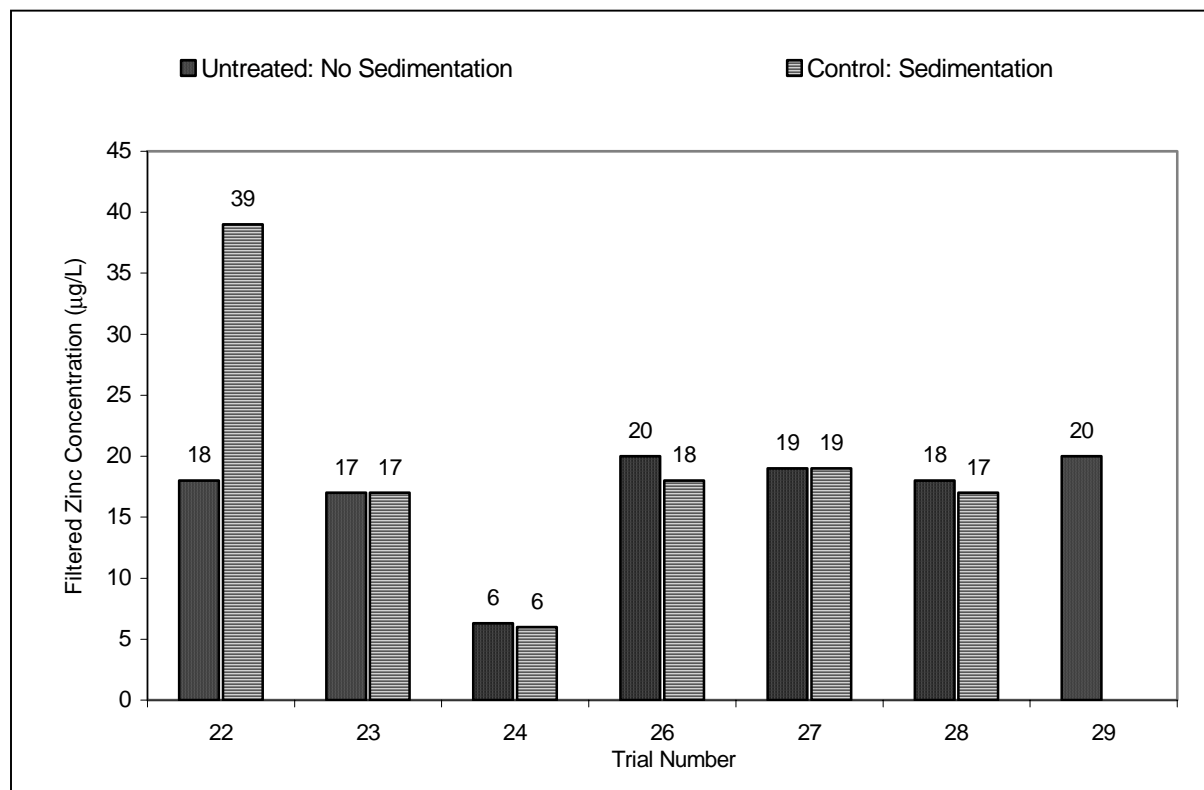


Figure 3-6. Filtered Zinc Concentrations

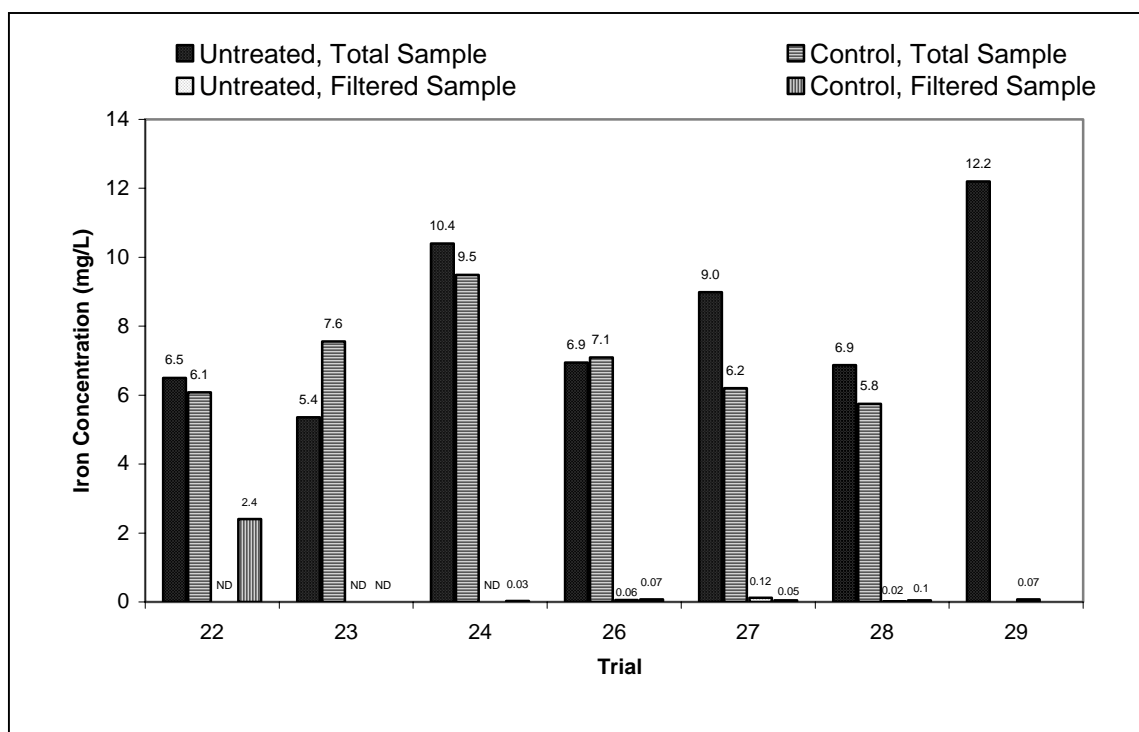


Figure 3-7. Total and Filtered Iron Concentrations

3.4.1 Aluminum Sulfate (Alum) Treatment

The metal results obtained when jar testing with aluminum sulfate did not indicate consistent trends. For example, at 4°C, removal of chromium, copper, and zinc was generally better at the lower alum doses than at the higher alum doses. The opposite was true for iron and lead. At 15°C, however, removal of all metals was generally better at a dose of 100 mg/L than at a dose of 50 mg/L. An aluminum sulfate dose of 100 mg/L was optimum for metals removal, and therefore was chosen for purposes of comparing metals removal with different coagulants later in this section. A dose of 100 mg/L aluminum sulfate was also the optimum dose for removal of solids as discussed previously.

3.4.2 Ferric Chloride Treatment

Total and filtered chromium, total and filtered copper, total lead, and total zinc concentrations were reduced when ferric chloride was dosed at 250 mg/L at 4°C. However, because of the alkalinity demand and sludge volume produced at 250 mg/L, this dose is not recommended. The 32 µg/L total chromium concentration for the sample dosed with 100 mg/L of ferric chloride at 15°C is questionable. This result is extremely high and well outside the upper range of normal untreated and control sample total chromium concentrations as indicated in Table 3-16 (7.3 µg/L and 6.1 µg/L, respectively). Based on this result, total chromium was not used for ranking coagulant metal removal performance.

Table 3-16. Total Metal Summary Statistics for Untreated and Control Samples

Sample	Chromium, Total (µg/L)		Copper, Total (µg/L)		Iron, Total (mg/L)		Lead, Total (µg/L)		Zinc, Total (µg/L)	
	Mean Total	95% Confidence Limit	Mean (a)	95% Confidence Limit	Mean (a)	95% Confidence Limit	Mean Total	95% Confidence Limit	Mean Total	95% Confidence Limit
Untreated (b)	5.7	4.0 to 7.3	18.7	13.1 to 24.3	8.2	6.3 to 10.0	7.7	6.5 to 9.0	91	60 to 122
Control (c)	5.0	3.8 to 6.1	17.1	12.8 to 21.3	7.0	5.8 to 8.2	6.2	5.5 to 6.8	78	49 to 108

- (a) The untreated and control means are not statistically different. See Appendix D for summary of statistical test results.
 (b) Untreated samples did not undergo sedimentation or coagulant treatment.
 (c) Control samples did undergo sedimentation, but not coagulant treatment.

Table 3-17. Filtered Metal Summary Statistics for Untreated and Control Samples

Sample	Chromium, Filtered (µg/L)		Copper, Filtered (µg/L)		Iron, Filtered (mg/L)		Lead, Filtered (µg/L)		Zinc, Filtered (µg/L)	
	Mean (a)	95% Confidence Limit	Mean (a)	95% Confidence Limit	Mean (a)	95% Confidence Limit	Mean	95% Confidence Limit	Mean (a)	95% Confidence Limit
Untreated (b)	1.6	1.4 to 1.7	5.3	3.8 to 6.7	0.06	0.03 to 0.09	---	---	17	12 to 21
Control (c)	1.7	1.4 to 2.4	7.1	4.3 to 9.9	0.4	<0 to 1.5	---	---	19	10 to 29

- (a) The untreated and control means are not statistically different. See Appendix D for summary of statistical test results.
 (b) Untreated samples did not undergo sedimentation or coagulant treatment.
 (c) Control samples did undergo sedimentation, but not coagulant treatment.

Table 3-18. Metal Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (degrees C)	Sample Date	Chromium, Total (µg/L)	Chromium, Filtered (µg/L)	Copper, Total (µg/L)	Copper, Filtered (µg/L)	Iron, Total (mg/L)	Iron, Filtered (mg/L)	Lead, Total (µg/L)	Lead, Filtered (µg/L)	Zinc, Total (µg/L)	Zinc, Filtered (µg/L)
Untreated	Mean	Varies	Varies	5.7	1.6	18.7	5.3	8.2	0.06	7.7	Insufficient detections	91	17
Control	Mean	Varies	Varies	5.0	1.7	17.1	7.1	7.0	0.4	6.2	Insufficient detections	78	19
Control	Lower 95% Confidence Interval Limit			3.8	1.4	12.8	4.3	5.8	<0	5.5	----	49	10
Reporting Limit				1.0	1.0	1.0	1.0	0.02	0.02	1.0	1.0	5.0	5.0
Aluminum Sulfate (Alum)													
5	24	4	12/3/2001	2.1	1.3	7.4	1.4	9.65	0.02	8.7	ND	17	5.8
20	24	4	12/3/2001	2.4	ND	6.0	1.2	9.34	ND	8.1	ND	15	5.7
50	24	4	12/3/2001	2.8	ND	6.9	1.4	9.07	0.02	ND	ND	14	5.8
100	24	4	12/3/2001	3.7	1.8	11	4.1	2.88	ND	2.4	ND	50	18
150	24	4	12/3/2001	3.5	1.7	11	2.6	2.53	ND	2.2	ND	46	15
50	30	15	12/10/2001	7.1	1.7	26	5.2	10.3	0.04	8.5	ND	120	8.6
100	30	15	12/10/2001	5.5	1.5	13	4.8	4.03	ND	3.5	ND	66	8.8
Ferric Chloride													
5	26	4	12/4/2001	5.7	2.7	22	7.1	7.17	0.17	6.8	ND	95	18
20	26	4	12/4/2001	7.8	1.7	23	6.1	9.92	0.35	7.6	ND	100	23
50	26	4	12/4/2001	8.7	1.4	25	5.3	13.7	0.12	7.6	ND	100	28
100	26	4	12/4/2001	5.7	1.5	15	6.5	5.53	0.07	1.7	ND	46	27
250	26	4	12/4/2001	3.6	1.1	6.4	2.3	9.15	0.04	ND	ND	24	21
50	30	15	12/10/2001	9.9	1.7	27	6.2	14.8	0.12	7.9	ND	110	28
100	30	15	12/10/2001	32	1.6	20	4.2	13.0	0.05	4.5	ND	77	20
JC 1670													
2	22	4	11/28/2001	5.0	1.5	18	4.3	6.27	ND	6.9	ND	97	16
5	22	4	11/28/2001	4.0	1.5	15	3.9	4.74	ND	5.0	ND	77	16
20	22	4	11/28/2001	4.2	1.6	13	1.5	4.31	ND	5.2	ND	78	14
50	22	4	11/28/2001	4.5	1.2	15	1.5	5.23	0.03	6.5	ND	91	13
100	22	4	11/28/2001	4.5	1.0	15	1.5	4.73	ND	6.8	ND	92	15
5	30	15	12/10/2001	7.2	1.6	27	6.3	9.78	0.03	8.2	ND	120	15
20	30	15	12/10/2001	2.1	1.8	4.6	2.8	0.64	ND	ND	ND	20	12

Note: Bolted values are less than or equal to the lower 95% confidence limit for the control samples.

Table 3-18. Metal Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (degrees C)	Sample Date	Chromium, Total (µg/L)	Chromium, Filtered (µg/L)	Copper, Total (µg/L)	Copper, Filtered (µg/L)	Iron, Total (mg/L)	Iron, Filtered (mg/L)	Lead, Total (µg/L)	Lead, Filtered (µg/L)	Zinc, Total (µg/L)	Zinc, Filtered (µg/L)
Untreated	Mean	Varies	Varies	5.7	1.6	18.7	5.3	8.2	0.06	7.7	Insufficient detections	91	17
Control	Mean	Varies	Varies	5.0	1.7	17.1	7.1	7.0	0.4	6.2	Insufficient detections	78	19
Control	Lower 95% Confidence Interval Limit			3.8	1.4	12.8	4.3	5.8	<0	5.5	----	49	10
Reporting Limit				1.0	1.0	1.0	1.0	0.02	0.02	1.0	1.0	5.0	5.0
Pass C													
5	27	4	12/4/2001	11	1.7	24	7.0	7.07	0.07	6.6	ND	95	20
20	27	4	12/4/2001	5.7	4.3	21	6.3	6.68	0.07	6.5	ND	97	22
50	27	4	12/4/2001	5.1	4.2	18	3.6	5.39	0.04	5.4	ND	83	17
100	27	4	12/4/2001	2.9	1.8	6.4	2.6	0.90	ND	1.0	ND	35	25
250	27	4	12/4/2001	4.9	2.4	14	1.3	4.06	ND	4.0	ND	72	30
5	28	15	12/4/2001	5.3	1.5	21	6.6	6.42	0.05	6.7	ND	94	17
20	28	15	12/4/2001	5.3	1.6	22	6.1	6.44	0.05	6.6	ND	93	14
50	28	15	12/4/2001	3.7	1.4	12	3.7	3.26	ND	3.0	ND	54	13
100	28	15	12/4/2001	2.1	12	4.7	3.0	0.48	0.03	ND	ND	26	19
250	28	15	12/4/2001	2.3	1.7	13	2.5	0.55	ND	ND	ND	23	14
Superfloc A 1849													
1	33	4	12/11/2001	6.8	2.4	18	10	5.14	0.03	4.8	ND	71	18
1.5	31	4	12/11/2001	5.6	2.9	17	8.0	5.06	0.05	4.5	ND	68	17
2.5	31	4	12/11/2001	4.3	2.7	13	7.7	3.67	0.04	3.1	ND	52	17
3.5	31	4	12/11/2001	3.7	2.7	11	6.3	2.79	0.04	2.5	ND	44	17
1.5	32	15	12/11/2001	5.7	2.4	11	7.2	2.92	0.02	2.6	ND	44	16
2.5	32	15	12/11/2001	4.1	1.9	12	6.9	3.36	0.02	3.0	ND	49	16
Westchlor 950S													
5	31	4	12/11/2001	6.6	2.7	21	6.5	8.08	0.04	7.5	ND	100	17
20	23	4	11/28/2001	5.5	1.7	19	3.9	6.92	ND	7.5	ND	100	14
20	31	4	12/11/2001	7.2	2.6	23	4.4	8.53	0.03	7.9	ND	110	14
50	23	4	11/28/2001	2.4	1.5	4.5	2.2	1.10	ND	1.1	ND	30	16
50	31	4	12/11/2001	3.1	2.6	5.8	2.7	1.15	ND	1.0	ND	29	18
55	23	4	11/28/2001	2.1	1.4	4.2	2.1	0.65	ND	ND	ND	24	16
100	23	4	11/28/2001	5.2	1.4	18	1.6	6.02	ND	6.5	ND	93	16
250	23	4	11/28/2001	5.5	1.5	20	2.9	6.65	ND	6.8	ND	100	24
2	29	15	12/10/2001	7.6	1.7	27	7.2	10.1	0.05	8.6	ND	130	14
5	29	15	12/10/2001	6.9	1.7	23	6.1	9.00	0.04	7.6	ND	110	14
20	29	15	12/10/2001	8.3	1.7	26	5.7	9.96	0.04	8.3	ND	120	12
50	29	15	12/10/2001	2.7	1.5	5.5	2.8	0.84	ND	ND	ND	25	13
100	29	15	12/10/2001	5.6	1.4	13	1.6	4.05	0.02	3.5	ND	57	10

Note Bolded values are lower than or equal to the lower 95% confidence interval for the control samples

Elevated total copper and total iron concentrations were also reported when ferric chloride was dosed with 100 mg/L at 15°C, although only the iron concentration was outside of the control sample mean upper limit (8.2 µg/L). Ferric chloride is an iron compound; therefore, it is not unexpected that iron concentrations could increase if optimum coagulation and sedimentation do not occur. The 100 mg/L dose of ferric chloride resulted in somewhat less metals removal than a dose of 250 mg/L; however, the 100 mg/L dose was selected for use in later comparisons between coagulants because of the lower alkalinity demand and sludge volume produced at this lower dose.

3.4.3 JC 1670 Treatment

At 15°C a JC 1670 dose of 20 mg/L resulted in equal or better metals removal than the 5 mg/L dose for all constituents except filtered chromium. The results of the 4°C tests were more variable. The 20 mg/L dose at 4°C was equal to or better than other doses for total and filtered copper, total iron, and total lead. For the other metals, the optimal JC 1670 dose was often 5 mg/L but sometimes was 50 mg/L or 100 mg/L. The total copper concentration after 5 mg/L of JC 1670 was dosed at 15°C was high (27 µg/L), and outside of the upper limit of the 95th confidence interval for the control sample mean (21 µg/L). The performance of JC 1670 at 15 °C was improved when the dose was increased to 20 mg/L. For purposes of comparison with other coagulants, the 20 mg/L dose was selected, although this dose resulted in slightly lower metal reductions in some cases. This was also the dose that best removed solids and nutrients from the storm water tested.

3.4.4 Pass C Treatment

Pass C dosed at 100 mg/L at both 4°C and 15°C reduced the concentrations of total chromium, total and filtered copper, total iron, total lead, and total zinc. The filtered chromium concentration of 12 µg/L reported for the Pass C 100 mg/L sample at 15°C is questionable. This filtered sample result is significantly greater than the 2.1 µg/L total chromium concentration reported for this same sample and is not observed in the other total/filtered datasets. Therefore, this filtered chromium result is considered to be anomalous and thusly, the filtered chromium data were not used for ranking coagulant performance. The Pass C dose chosen for comparison with other coagulants was 100 mg/L, which is the optimum dose for solids and nutrients removals for the storm water tested.

3.4.5 Superfloc A1849 Treatment

Total chromium, copper, iron, lead, and zinc concentrations were minimized in the 4°C tests when the storm water was dosed with 3.5 mg/L of Superfloc A1849 (the maximum NSF recommended dose). Filtered chromium and iron concentrations were minimized at a lower dose. A 3.5 mg/L dose was not tested at 15°C. Of the two doses tested at 15 °C, metals removal was the same or better at the 2.5 mg/L dose for all the metals tested except total copper, iron, lead, and zinc. Where the 1.5 mg/L dose produced better results, the removals

were only marginally better. For comparison with other coagulants, the 2.5 mg/L dose was selected.

3.4.6 Westchlor 950S Treatment

The optimum dose for metals removal with Westchlor 950S was most often 50 mg/L at both temperatures tested. This dose was chosen for the comparison between coagulants. This dose also performed best for solids and nutrient removal.

3.4.7 Metals Summary

Metal results for the various coagulants at the optimum doses selected are summarized and ranked in Table 3-19 (4°C) and Table 3-20 (15°C). A ranking value of “one” corresponds to the lowest respective metal concentration. These temperature-dependent rankings are combined into an overall ranking in Table 3-21. In each of the tables, the coagulants are ranked according to metals removal performance at the selected dose. The rankings for each metal evaluated are, then, summed. A final ranking of these sums was performed as shown in Table 3-21. Pass C (100 mg/L), JC 1670 (20 mg/L), and Westchlor 950S (50 mg/L) were the three coagulants that performed best without requiring the addition of NaOH.

Two other methods of ranking the coagulants for metals removal were also developed. The ranking based on total metal concentration reduction (i.e., without metal-specific ranking) is presented in Table 3-22. Pass C is ranked best by this concentration method. Rankings based solely on total iron removal are presented in Table 3-23. Pass C is ranked best at removing iron, the only metal currently regulated in Lake Tahoe Basin storm water.

3.5 Aluminum

Aluminum is presented separately from the other metals because four of the six coagulants tested are aluminum-based. The potential for these coagulants to increase residual aluminum concentrations was investigated. The aquatic toxicity criteria for aluminum is not specifically listed in the California Toxics Rule (USEPA, 2000); however, recommended aluminum ambient water quality objectives can be used to set numeric limitations. The recommended chronic aluminum criterion is 87 µg/L and the acute aluminum criterion is 750 µg/L, based on pH values in the 6.5 to 9.0 range (USEPA, 2002). Outside of this pH range, aluminum is believed to be more toxic. Therefore, the discussion related to pH adjustments necessary for some coagulants tested is included with the presentation of the aluminum results. The aluminum results for the untreated (without sedimentation) and control (with sedimentation) samples are presented first, followed by presentations of the aluminum results for the individual coagulants tested. The total and filtered aluminum concentrations reported from the analyses of replicate untreated and control samples were compared to assess the variability observed over the course of the study. Figures 3-8 and 3-9 illustrate the total and filtered aluminum concentrations detected in these QA/QC samples.

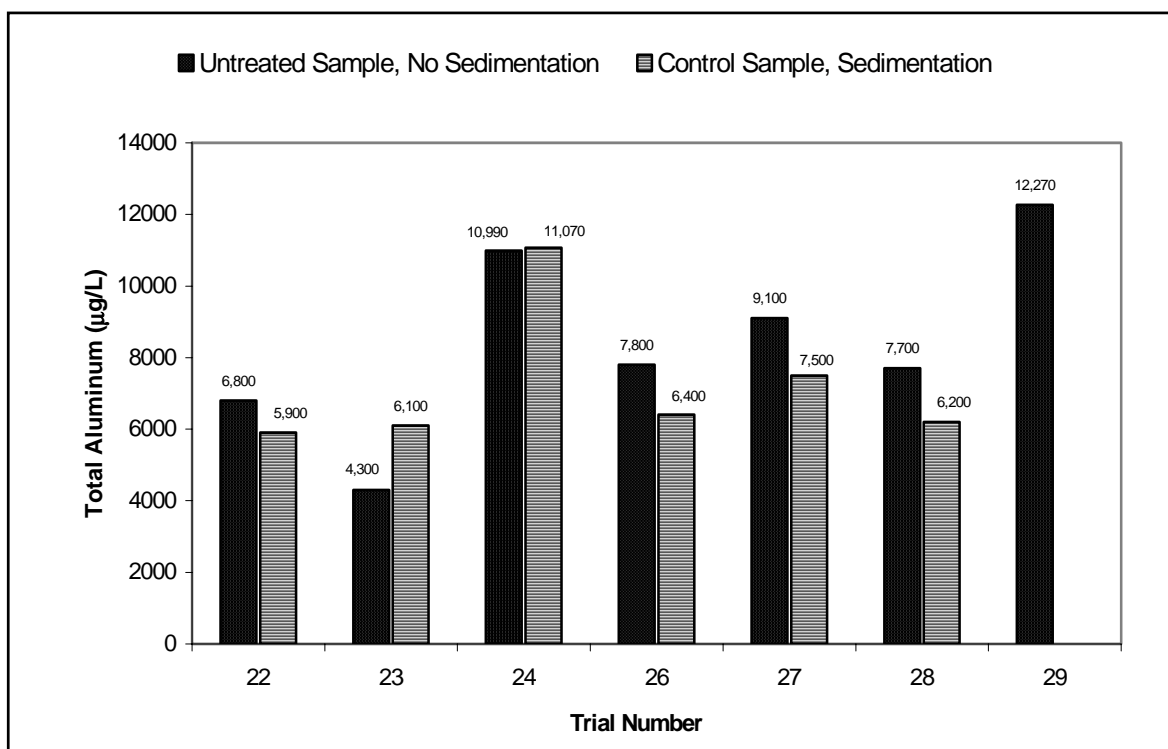


Figure 3-8. Total Aluminum Concentrations

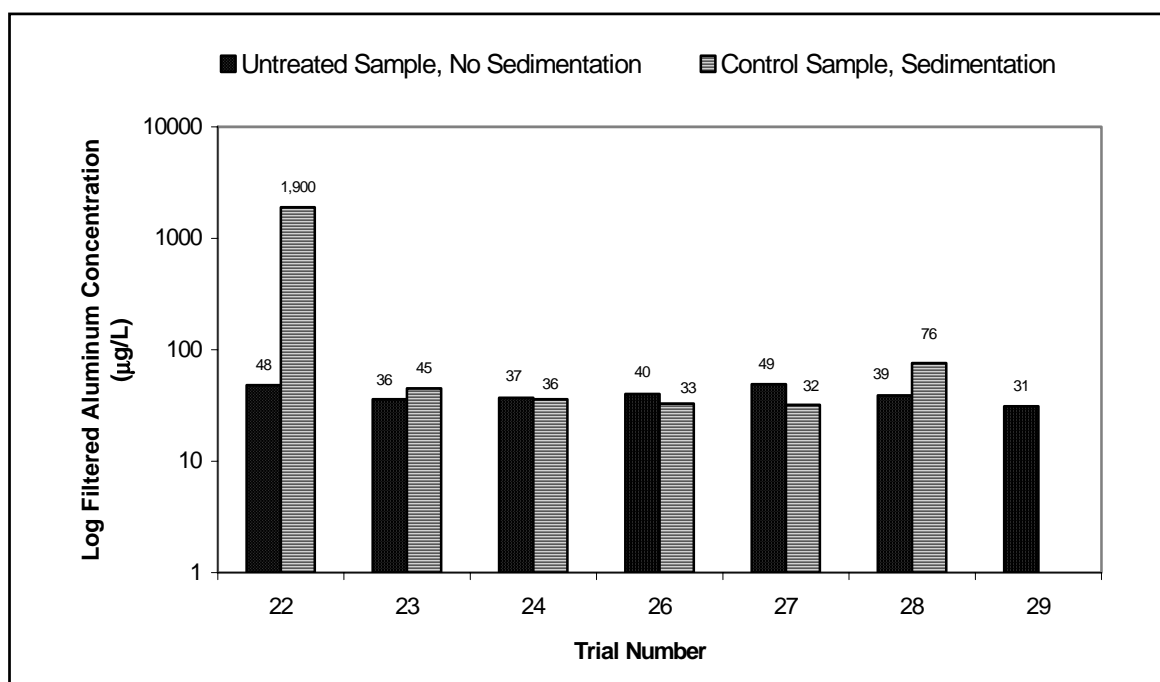


Figure 3-9. Log Filtered Aluminum Concentrations

Table 3-19. Metals Summary Relative Rankings: 4°C

Coagulant	Dose (mg/L)	Chromium, Total		Chromium, Filtered		Copper, Total		Copper, Filtered		Iron, Total		Iron, Filtered		Lead, Total		Lead, Filtered		Zinc, Total		Zinc, Filtered		Ranking Sum	Metal 4°C Rank
		(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(mg/L)	Rank	(mg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank		
Aluminum Sulfate	100	3.7	3	1.8	3	11	3	4.1	4	2.88	3	ND(<0.02)	1	2.4	4	ND(<1.0)	1	50	4	18	4	30	3
Ferric Chloride	100	5.7	6	1.5	1	15	5	6.5	5	5.53	6	0.07	6	1.7	3	ND(<1.0)	1	46	3	27	6	42	5
JC 1670	20	4.2	4	1.6	2	13	4	1.5	1	4.31	5	ND(<0.02)	1	5.2	6	ND(<1.0)	1	78	6	14	1	31	4
Pass C	100	2.9	1	1.8	3	6.4	2	2.6	3	0.90	1	ND(<0.02)	1	1.0	1	ND(<1.0)	1	35	2	25	5	20	2
Superfloc A1849	2.5	4.3	5	2.7	5	13	4	7.7	6	3.67	4	0.04	5	3.1	5	ND(<1.0)	1	52	5	17	2	42	6
Westchlor 950S (a)	50	2.8	2	2.0	4	5.2	1	2.4	2	1.25	2	ND(<0.02)	1	5.0	2	ND(<1.0)	1	29.5	1	17	2	18	1

Note: Bolded values are lower than or equal to the lower 95% confidence interval for the control samples

(a) Average of 50mg/L Westchlor 950S dose results.

Table 3-20. Metals Summary Relative Rankings: 15°C

Coagulant	Dose (mg/L)	Chromium, Total (a)		Chromium, Filtered (a)		Copper, Total		Copper, Filtered		Iron, Total		Iron, Filtered		Lead, Total		Lead, Filtered		Zinc, Total		Zinc, Filtered		Ranking Sum	Metal 15°C Rank
		(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(mg/L)	Rank	(mg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank	(µg/L)	Rank		
Aluminum Sulfate	100	5.5	---	1.5	---	13	5	4.8	5	4.03	5	ND(<0.02)	1	3.5	5	ND(<1.0)	1	66	5	8.8	1	28	4
Ferric Chloride	100	32 (a)	---	1.6	---	20	6	4.2	4	13.0	6	0.05	6	4.5	6	ND(<1.0)	1	77	6	20	6	41	6
JC 1670	20	2.1	---	1.8	---	4.6	1	2.8	1	0.64	2	ND(<0.02)	1	ND(<1.0)	1	ND(<1.0)	1	20	1	12	2	10	1
Pass C	100	2.1	---	12 (a)	---	4.7	2	3.0	3	0.48	1	0.03	5	ND(<1.0)	1	ND(<1.0)	1	26	3	19	5	21	3
Superfloc A1849	2.5	4.1	---	1.9	---	12	4	6.9	6	3.36	4	0.02	4	3.0	4	ND(<1.0)	1	49	4	16	4	31	5
Westchlor 950S	50	2.7	---	1.5	---	5.5	3	2.8	2	0.84	3	ND(<0.02)	1	ND(<1.0)	1	ND(<1.0)	1	25	2	13	3	16	2

Note: Bolded values are lower than or equal to the lower 95% confidence interval

(a) These results is strongly suspected of being anomalous, therefore to avoid biasing the ranking results, the total and filtered chromium results were not used for ranking coagulant effectiveness.

Table 3-21. Overall Metals Rankings: 4°C and 15°C

Coagulant	Dose (mg/L)	Metal 4°C Rank	Metal 15°C Rank	Ranking Sum	Metal Ranking
Aluminum Sulfate	100	3	4	7	4
Ferric Chloride	100	5	6	11	5
JC 1670	20	4	1	5	3
Pass C	100	2	3	5	2
Superfloc A1849	2.5	6	5	11	5
Westchlor 950S	50	1	2	3	1

Table 3-22. Summation of Total Metals Concentrations

Coagulant	Dose (mg/L)	Metal 4°C Mass Sum (mg/L)	Metal Mass 4°C Rank	Metal 15°C Mass Sum (mg/L)	Metal Mass 15°C Rank	Ranking Sum	Metal Ranking
Aluminum Sulfate	100	3.0	3	4.1	5	8	4
Ferric Chloride	100	5.6	6	13	6	12	5
JC 1670	20	4.4	5	0.68	2	7	3
Pass C	100	0.98	1	0.56	1	2	1
Superfloc A1849	2.5	3.7	4	3.5	4	8	4
Westchlor 950S	50	1.3	2	0.89	3	5	2

Table 3-23. Total Iron Metals Rankings: 4°C and 15°C

Coagulant	Conc. (mg/L)	Metal 4°C Rank	Metal 15°C Rank	Ranking Sum	Total Iron Ranking
Aluminum Sulfate	100	3	5	8	4
Ferric Chloride	100	6	6	12	5
JC 1670	20	5	2	7	3
Pass C	100	1	1	2	1
Superfloc A1849	2.5	4	4	8	4
Westchlor 950S	50	2	3	5	2

The scale for the filtered aluminum concentration axis is logarithmic so that the high filtered aluminum concentration reported for the Trial 22 control sample does not dominate Figure 3-9. The high filtered aluminum concentration (1,900 µg/L) reported for the Trial 22 control sample is questionable and the resultant sample dataset variability (3.0 coefficient of variation) is outside of the range of expected variability based on the coefficient of variation generally calculated for the other parameters measured (0.1 to 0.5, see Table 3-2). Although the total aluminum concentration for Trial 22 was approximately 6,000 µg/L, it is unlikely for conditions to exist that would result in such a high filtered concentration (1,900 µg/L), especially since all other filtered untreated and filtered control sample aluminum concentrations were less than 100 µg/L. To investigate a possible systematic error, the filtered concentrations for the other metals analyzed in Trial 22 were reviewed. The Trial 22 control filtered zinc concentration was two times higher than the next highest control filtered zinc concentration, suggesting a possible trend. Other Trial 22 control filtered metal concentrations (e.g., chromium, and copper) were not similarly elevated in comparison with the Trial 23, Trial 24, Trial 26, Trial 27, and Trial 28 control filtered metal sample results. Aluminum is not readily dissolved in near to neutral pH conditions typical of natural waters. The 6.9 pH reported for Trial 22 should not result in the high proportion of dissolved aluminum observed based on solubility controls associated with aluminum speciation modeling (Hem, 1985). One possible explanation for this high result is “memory interference” from sample to sample in the ICP/MS instrument used by the laboratory for aluminum analyses (EPA Method 200.8). The sample analyzed preceding Trial 22 was from dosing JC 1670 at 100 mg/L, which had a very high filtered aluminum concentration (1,600 µg/L) capable of causing interference.

A summary of the reported detections, means, and 95 percent confidence interval limits are presented in Table 3-24 for the total and filtered aluminum results of the untreated (no sedimentation) and control (with sedimentation) samples. Control sample summary statistics were obtained for datasets with and without the suspected outlier (1,900 µg/L filtered aluminum result). The jar test experimental results, including aluminum analyses, are reported in Appendix C (summary reports), Appendix H (original lab reports), and Appendix D (statistical analyses).

Table 3-24. Aluminum Statistics for Influent and Control Samples

Sample	Aluminum, Total Mean (µg/L) (a)	Aluminum, Total 95% Confidence Limit (µg/L)	Aluminum, Filtered Mean (µg/L) (a)	Aluminum, Filtered 95% Confidence Limit (µg/L)
Untreated	8,423	6,377 to 10,469	40	35 to 45
Control	7,195	5,278 to 9,112	354	<0 to 1,212
Control (b)	7,195	5,278 to 9,112	44	25 to 64

(a) The untreated and treated means are not statistically different. See Appendix D for summary of the statistical test results.

(b) The DAT statistics were run with the control sample 1,900 µg/L filtered aluminum result removed (n=5). See Appendix D for summaries of the DAT statistics run with 1,900 µg/L and without this suspected outlier.

The aluminum concentrations resulting from jar tests dosed with coagulants conducted at 4°C and 15°C are presented in Table 3-25. The lower 95 percent confidence interval limit obtained (with the 1,900 µg/L filtered aluminum result removed) was also indicated and used as a comparative means to identify substantial reductions in aluminum (noted in bold).

Table 3-25. Aluminum Concentrations in Supernatant after Treatment

Coagulant and Dose (mg/L)	Trial Number	Temperature (°C)	Sample Date	Total Aluminum (µg/L)	Filtered Aluminum (µg/L) (a)
Untreated		Mean		8,423	40
Control		Mean		7,195	44
Control	95% confidence interval limits			5,278 to 9,112	25 to 64
Aluminum Sulfate (Alum)					
5	24	4	12/3/01	11,410	59
20	24	4	12/3/01	12,740	64
50	24	4	12/3/01	10,820	57
100	24	4	12/3/01	5,500	22
150	24	4	12/3/01	6,900	26
50	30	15	12/10/01	12,270	42
100	30	15	12/10/01	6,325	19
Ferric Chloride					
5	26	4	12/4/01	7,700	29
20	26	4	12/4/01	8,200	26
50	26	4	12/4/01	8,100	38
100	26	4	12/4/01	2,000	11
250	26	4	12/4/01	270	ND (<10)
50	30	15	12/10/01	10,090	13
100	30	15	12/10/01	5,438	ND (<10)
JC 1670					
2	22	4	11/28/01	5,900	25
5	22	4	11/28/01	4,600	27
20	22	4	11/28/01	6,700	ND (<10)
50	22	4	11/28/01	9,800	130
100	22	4	11/28/01	16,000	1,300
5	30	15	12/10/01	10,870	20
20	30	15	12/10/01	1,222	ND (<10)
Pass C					
5	27	4	12/4/01	8,900	58
20	27	4	12/4/01	8,500	54
50	27	4	12/4/01	8,600	30
100	27	4	12/4/01	2,800	22

Notes: Results shown bold are less than or equal to the lower 95% confidence limit for control total aluminum (5,278 µg/L) and filtered aluminum (25 µg/L) means.

Table 3-25. Aluminum Concentrations in Supernatant after Treatment

Coagulant and Dose (mg/L)	Trial Number	Temperature (°C)	Sample Date	Total Aluminum (µg/L)	Filtered Aluminum (µg/L) (a)
Untreated		Mean		8,423	40
Control		Mean		7,195	44
Control	95% confidence interval limits			5,278 to 9,112	25 to 64
Pass C (continued)					
250	27	4	12/4/01	15,000	17
5	28	15	12/4/01	7,800	36
20	28	15	12/4/01	8,600	42
50	28	15	12/4/01	5,500	26
100	28	15	12/4/01	1,600	13
250	28	15	12/4/01	3,700	15
Superfloc A1849					
1	33	4	12/11/01	5,169	26
1.5	31	4	12/11/01	4,984	26
2.5	31	4	12/11/01	3,591	25
3.5	31	4	12/11/01	2,810	26
1.5	32	15	12/11/01	2,902	24
2.5	32	15	12/11/01	3,489	29
Westchlor 950S					
5	31	4	12/11/01	8,095	33
20	23	4	11/28/01	8,000	20
20	31	4	12/11/01	9,499	23
50	23	4	11/28/01	1,600	20
50	31	4	12/11/01	2,116	ND (<10)
55	23	4	11/28/01	1,100	14
100	23	4	11/28/01	12,000	10
250	23	4	11/28/01	23,000	13
2	29	15	12/10/01	10,600	29
5	29	15	12/10/01	9,387	31
20	29	15	12/10/01	10,700	27
50	29	15	12/10/01	1,900	12
100	29	15	12/10/01	8,500	ND (<10)

Notes: Results shown bold are less than or equal to the lower 95% confidence limit for control total aluminum (5,278 µg/L) and filtered aluminum (25 µg/L) means.

- (a) The filtered aluminum mean concentration and 95% confidence interval limits from the control sample data that are reported in Table 3-24 were the concentrations obtained after an obvious outlier (1,900 µg/L) was removed from the dataset.

3.5.1 Aluminum Sulfate (Alum) Treatment

Aluminum sulfate is a chemical coagulant that contains aluminum and consumes alkalinity to form floc. For clarity, aluminum sulfate will be referred to in this section as “alum”, its common name. Low alkalinity, in the range of 15.5 to 20.5 mg/L was reported for the storm water tested (see Appendix D, Summary Statistics). Therefore, a 1.5 molar sodium hydroxide (1.5 M NaOH) solution was used to maintain the pH between 6.0 and 7.0. The amount of NaOH added heretofore is referenced as millimoles (millimoles of 1.5 moles/liter NaOH). Additions of NaOH for the second set of variable temperature jar tests were estimated based on the amounts of NaOH used during the first set of preliminary jar tests.

Sodium hydroxide additions were needed when alum was dosed at concentrations higher than 5 mg/L. As the alum dose increases, the amount of NaOH necessary to maintain pH 6 to 7 increases. For example, when 20 mg/L of alum was dosed, 0.075 millimoles of NaOH were needed to maintain the pH between 6 and 7. When 150 mg/L of alum was dosed, 0.87 millimoles were needed to maintain the pH between 6 and 7. As indicated in Table 3-25, the concentrations of aluminum remaining in the sample supernatant after settling are actually higher when lower concentrations of alum are added, reflecting an accumulation of aluminum in the water column when the alum dose is insufficient to cause large, settling flocs. Flocs that were smaller and did not settle within 30 minutes may have been present in the samples that underwent laboratory analyses. At high alum dosages with NaOH additions, the flocs produced were larger and settled within the 30-minute sedimentation time.

The lowest total and filtered aluminum supernatant concentrations after 30 minutes of settling occurred with an alum dose of 100 mg/L, with 0.45 millimoles NaOH added to maintain pH. Based on aluminum concentrations, there does not appear to be a significant temperature effect that results in better coagulation performance at 15°C versus 4°C.

3.5.2 Ferric Chloride Treatment

Ferric chloride is a coagulant that does not contain aluminum but does contain iron and requires alkalinity to form floc. Therefore, similar to the alum tests, NaOH was added in conjunction with ferric chloride doses, as needed, to maintain the solution pH in the 6 to 7 range. Aluminum concentrations resulting from jar tests when ferric chloride was the coagulant dosed are summarized in Table 3-25.

When ferric chloride was added in concentrations exceeding 20 mg/L, 1.5 M NaOH was added to maintain the pH of the solution between 6.0 and 7.0. The amounts of NaOH needed increased with increasing ferric chloride doses. For example, the 50 mg/L ferric chloride dose required the addition of 0.075 millimoles NaOH to maintain pH. The 250 mg/L ferric chloride dose required the addition of 2.4 millimoles NaOH to maintain pH. The amount of NaOH that was necessary to maintain pH was higher for ferric chloride than for aluminum sulfate for a given dose of coagulant product.

The concentrations of aluminum remaining in the sample supernatant after settling were significantly lower when higher doses of ferric chloride were added and good flocculation occurred. The ferric chloride dose that provided the lowest total and filtered aluminum concentrations at 4°C was the highest dose tested, 250 mg/L. The 250 mg/L ferric chloride dose required a disproportionately larger NaOH addition (2.4 millimoles) compared to the 100 mg/L ferric chloride dose NaOH addition (0.45 millimoles). Additionally, the 250 mg/L ferric chloride dose produced a relatively large amount of sludge. For these reasons, the 100 mg/L ferric chloride was judged to be the more desirable dose. The 100 mg/L ferric chloride dose also provided low dissolved aluminum concentrations at 15°C. Based on the aluminum results for the 100 mg/L ferric chloride dosed jar tests, there does not appear to be a significant temperature effect that results in better coagulant performance at 15°C versus 4°C.

3.5.3 JC 1670 Treatment

JC 1670 is an advanced cationic polymeric coagulant that contains aluminum, but does not require alkalinity to form floc. JC 1670 contains partially hydrolyzed aluminum in the form of polyaluminum hydroxchloride, and thusly reduces the alkalinity needed to form floc. Additionally, this coagulant solution contains a cationic polymer that decreases the coagulant concentrations necessary for the formation of floc that settle quickly. Aluminum concentrations resulting from jar tests in which JC 1670 was the coagulant added are summarized in Table 3-25.

The aluminum concentrations that resulted from using JC 1670 indicate that total and filtered aluminum appear to increase once JC 1670 doses exceed about 20 mg/L. Flocculation is a surface charge process, so as concentrations of positively charged particles (aluminum and polymeric cations) increase with increasing JC 1670 dosing concentrations, the net charge on the suspended particles may change from negative to positive at some level of coagulant dosage resulting in same charge repulsion, i.e., poor or weak floc formation. Such coagulants perform poorly if overdosed.

As noted in the previous control sample results discussion, the anomalous high filtered control aluminum sample result immediately followed the analyses laboratory sample 0011723 which had a high filtered aluminum concentration (1,300 µg/L) as a result of dosing with 100 mg/L of JC 1670. The 100 mg/L dose of JC 1670 did not perform well suggesting that a significant portion of the 1,300 µg/L filtered aluminum in this sample may have been unreacted coagulant due to overdosing.

The concentration of JC 1670 that performed best, in terms of filtered aluminum, was 20 mg/L. At this JC 1670 dose, treatment performance (based on total aluminum) was better at 15°C as compared to 4°C. However, the potential to overdose with this coagulant, resulting in extremely high filtered aluminum concentrations, suggests that this coagulant

would require careful dose control if used in field applications. The 20 mg/L dose of JC 1670 also performed best for solids removal.

3.5.4 Pass C Treatment

Pass C is a coagulant that contains aluminum but does not require alkalinity to form floc; because Pass C contains aluminum in the form of polyaluminum chloride that has been pre-hydrolyzed. Aluminum concentrations resulting from jar tests when Pass C was the test coagulant are summarized in Table 3-25.

The aluminum concentrations that resulted from the testing of Pass C indicate that there may be relationships between aluminum concentration and dose, and between temperature and dose. An optimum dose that minimized the concentration of aluminum was found at 100 mg/L of Pass C. As doses increased beyond 100 mg/L, the total aluminum concentrations (but not filtered aluminum concentrations) increased. A partial explanation for this phenomenon of only total aluminum concentrations increasing with Pass C dose of 250 mg/L at 4°C may be that the available alkalinity decreased (from 12 mg/L to 8 mg/L), and the pH decreased (from 6.4 to 6.2). At this lower pH, floc formation and settling characteristics were not as good as at the higher pH. Thus, flocs (with their aluminum content) would not settle fully (and thus would show up in a total aluminum analysis), but the flocs in the sample would be removed by filtration (and thus would not show up in a filtered aluminum analysis). Similar but less dramatic findings were observed at 15°C. At 15 °C, the total aluminum concentration increased as Pass C doses increased to the 250 mg/L dose, although not to the same degree as had at 4°C (3,700 µg/L at 15 °C versus 15,000 µg/L at 4°C). At 15 °C, the filtered aluminum concentration increased slightly from 13 µg/L (100 mg/L dose) to 15 µg/L (250 mg/L dose), a less significant change than the decrease of filtered aluminum concentration from 22 µg/L (100 mg/L dose) to 17 µg/L (250 mg/L dose) at 4°C. Four of the five jar tests with Pass C had lower aluminum concentrations at 15°C than at 4°C for the same dose indicating a possible temperature relationship. The dose of Pass C that performed best, in terms of aluminum removal, was 100 mg/L.

3.5.5 Superfloc A1849 Treatment

Superfloc A1849 is an anionic polyacrylamide flocculant that does not contain aluminum and does not require alkalinity to form floc. Aluminum concentrations resulting from treatment using Superfloc A1849 are summarized in Table 3-25.

The results from total aluminum analyses show a possible relationship between aluminum concentrations and Superfloc A1849 doses. Additionally, there may also be a temperature relationship when Superfloc A1849 is dosed at 1.5 mg/L. At this dose, there was a nearly 50 percent reduction in aluminum concentrations when the jar test was conducted at 15°C as compared to 4°C. The dose of Superfloc A1849 that performed best, in terms of filtered aluminum removal, was not distinguishable.

3.5.6 Westchlor 950S Treatment

Westchlor 950S is a coagulant that contains aluminum but does not require alkalinity to form floc at lower doses. Aluminum concentrations resulting from treatment using Westchlor 950S are summarized in Table 3-25.

The aluminum concentrations that resulted from the use of Westchlor 950S indicate that there may be a relationship between aluminum concentration and dose. As the dose of Westchlor 950S increased, the concentration of total aluminum generally (though not uniformly) decreased until the optimum Westchlor 950S dose of 50 mg/L was reached. As dose concentrations of Westchlor 950S further increased, total aluminum concentrations increased. The Westchlor 950S data, based on aluminum concentrations, did not indicate that increased temperatures result in better performance.

The dose of Westchlor 950S that performed best at reducing aluminum concentrations was 50 mg/L. The 50 mg/L Westchlor 950 dose also reduced solids concentrations best.

3.5.7 Aluminum Summary

The data presented in this section were used to rank the coagulants based on 1) aluminum concentrations after sedimentation, and 2) the need for adding additional chemicals (e.g. NaOH) to maintain alkalinity. Only total aluminum results were used for ranking the coagulants and doses that were previously selected as performing best in terms of solids reductions. A ranking value of “one” corresponded to the lowest aluminum concentration. Pass C (dosed at 100 mg/L) and Westchlor 950S (dosed at 50 mg/L) were the coagulants that performed best without the addition of NaOH. The individual ranking values for the various coagulants tested at 4°C and 15°C are summarized in Tables 3-26 and 3-27, respectively. An overall ranking for the coagulants based on aluminum is presented in Table 3-28. Westchlor 950S was ranked best overall based on aluminum removal, Pass C was ranked second.

Table 3-26. Aluminum Summary Relative Rankings: 4 °C

Coagulant	Dose (mg/L)	Temp. (°C)	Aluminum Total (µg/L)	Total Aluminum at 4°C Ranking
Alum	100	4	5,500	5
Ferric Chloride	100	4	2,000	2
JC 1670	20	4	6,700	6
Pass C	100	4	2,800	3
Superfloc A1849	2.5	4	3,591	4
Westchlor 950S (a)	50	4	1,858	1

Note: Results shown bold are less than or equal to the lower 95% confidence limit for the control total aluminum mean (5,278 µg/L) and for control filtered mean (25 µg/L).

(a) The 50 mg/L Westchlor 950S results as presented were averaged.

Table 3-27. Aluminum Summary Relative Rankings: 15 °C

Coagulant	Dose (mg/L)	Temp. (°C)	Total Aluminum (µg/L)	Total Aluminum at 15 °C Ranking
Alum	100	15	6,325	6
Ferric Chloride	100	15	5,438	5
JC 1670	20	15	1,222	1
Pass C	100	15	1,600	2
Superfloc A1849	2.5	15	3,489	4
Westchlor 950S	50	15	1,900	3

Note: Results shown bold are less than or equal to the lower 95% confidence limit for the control total aluminum mean (5,278 µg/L) and for control filtered mean (25 µg/L).

Table 3-28. Overall Total Aluminum Rankings: 4°C and 15°C

Coagulant	Dose. (mg/L)	Metal 4°C Rank	Metal 15°C Rank	Ranking Sum	Overall Rank
Aluminum Sulfate	100	5	6	11	6
Ferric Chloride	100	2	5	7	3
JC 1670	20	6	1	7	3
Pass C	100	3	2	5	2
Superfloc A1849	2.5	4	4	8	5
Westchlor 950S	50	1	3	4	1

3.6 Conventional Parameters

The conventional parameters include calcium, magnesium, hardness, total alkalinity, bicarbonate alkalinity, carbonate alkalinity, hydroxide alkalinity, specific conductance, total dissolved solids (TDS), and pH. The conventional parameters are generally not considered pollutants unless the concentrations are very high; however, hardness (the molar sum of the divalent cations, including calcium and magnesium, which is expressed in terms of CaCO₃) is an important parameter when assessing metal toxicity limits (as discussed previously). Alkalinity was monitored because of its affect on coagulant performance (some coagulants tested needed NaOH to maintain pH and form flocs) and pH buffering. For example, if the alkalinity is reduced, then the water is more susceptible to pH changes. Changes that result in decreased pH will increase metal toxicity, and potentially have a harmful effect on water quality. The alkalinity and pH for the jar tests conducted using aluminum sulfate and ferric chloride were adjusted by the addition of NaOH; therefore, these parameters (while monitored) are not evaluated for all coagulants tested.

The carbonate alkalinity and hydroxide alkalinity results (reported with total alkalinity results) were non-detect for all jar test samples, and the bicarbonate alkalinity (reported with

total alkalinity results) equaled the total alkalinity. The presence and dominance of bicarbonate alkalinity was not an unexpected finding since the distribution of alkalinity amongst the various carbonate species depends on the pH of the sample, and carbonate equilibria. Therefore, only total alkalinity results are considered for comparison, and only when pH adjustments were not necessary to maintain pH values in the 6.0 to 7.0 range. It is important to recognize that in the case of most aluminum sulfate and ferric chloride doses, NaOH was added to supplement the samples' alkalinity, and maintain pH in the 6 to 7 range, which is suitable for effective treatment, as discussed previously. Generally, the specific conductance and total dissolved solids results increased roughly in proportion to the dosing, as would be expected since coagulants were added. Differences from this general trend remain unexplained.

The concentrations of conventional parameters observed in the untreated and control samples were not as variable as other parameter groups (see Appendices B and D). Summaries of the conventional parameter means and 95% confidence interval limits are presented in Table 2-29 and Table 3-30 for the untreated and control sample results.

Table 3-29. Conventional Parameters Summary Statistics for Untreated and Control Samples: Means

Sample	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO ₃)	pH (pH units)	Total Alkalinity (mg/L as CaCO ₃)	Specific Conductance (µmhos/cm)	Total Dissolved Solids (mg/L)
Untreated	6.9	3.2	31	7.0	18	384	278
Control	6.5	2.8	28	7.0	19	389	293

Note: 100% of untreated and control samples had detectable concentrations

Table 3-30. Conventional Parameters Statistics for Untreated and Control Samples: 95% Confidence Limits

Sample	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO ₃)	pH (pH units)	Total Alkalinity (mg/L as CaCO ₃)	Specific Conductance (µmhos/cm)	Total Dissolved Solids (mg/L)
Untreated	6.3 to 7.6	2.6 to 3.8	27 to 35	6.8 to 7.1	15 to 21	364 to 403	258 to 298
Control	6.1 to 7.0	2.4 to 3.1	25 to 30	6.8 to 7.1	17 to 21	367 to 411	265 to 321

To assist in evaluating conventional parameter removal performance, the lower 95% confidence interval limits about the mean of the control sample results were used as a comparative benchmark. The conventional parameter results for aluminum sulfate, ferric chloride, Superfloc A1849, JC 1670, Pass C, and Westchlor 950S jar test samples are presented in Table 3-31 and the alkalinity results are discussed below.

Table 3-31. Conventional Parameter Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (° C)	Sample Date	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO ₃)	pH (pH Units)	Total Alkalinity (mg/L as CaCO ₃)	Specific Conductance (µmhos/cm)	Total Dissolved Solids (mg/L)
Untreated		Mean		6.9	3.2	31	7.0	18	384	278
Control		Mean		6.5	2.8	28	7.0	19	389	293
Control		95% Confidence Interval Limit		6.1 to 7.0	2.4 to 3.1	25 to 30	6.8 to 7.1	17 to 21	367 to 411	265 to 321
Aluminum sulfate (a)										
5	24	4	12/3/2001	7.42	3.57	33	6.9	20	443	232
20	24	4	12/3/2001	6.81	3.48	31	6.9	16	442	260
50	24	4	12/3/2001	7.63	3.46	33	6.7	20	457	212
100	24	4	12/3/2001	5.43	0.46	15	6.8	14	481	240
150	24	4	12/3/2001	5.82	1.34	20	7.1	20	523	280
50	30	15	12/10/2001	7.85	3.65	35	6.3	12	415	260
100	30	15	12/10/2001	6.59	1.68	23	6.3	10	442	192
Ferric chloride (a)										
5	26	4	12/4/2001	6.40	2.72	27	6.9	18	374	296
20	26	4	12/4/2001	6.97	3.06	30	6.4	16	376	272
50	26	4	12/4/2001	7.13	3.22	31	6.1	22	384	296
100	26	4	12/4/2001	5.53	1.06	18	6.2	20	428	272
250	26	4	12/4/2001	4.87	0.69	15	6.5	18	515	332
50	30	15	12/10/2001	7.40	3.50	33	6.0	8	406	236
100	30	15	12/10/2001	6.73	2.07	25	6.0	10	446	260
JC 1670										
2	22	4	11/28/2001	6.37	2.64	27	7.0	16	388	292
5	22	4	12/10/2001	5.69	2.02	23	6.9	18	381	272
20	22	4	11/28/2001	6.06	2.00	23	6.9	20	407	280
50	22	4	11/28/2001	6.25	2.41	26	6.8	16	388	256
100	22	4	12/10/2001	6.29	2.21	25	6.6	18	399	280
5	30	15	11/28/2001	7.40	3.56	33	6.7	12	403	272
20	30	15	11/28/2001	4.91	0.62	15	6.8	12	390	248
Pass C										
5	27	4	12/4/2001	6.59	2.66	27	6.9	22	366	248
20	27	4	12/4/2001	6.62	2.76	28	6.9	20	375	304
50	27	4	12/4/2001	6.30	2.33	25	6.7	18	378	232
100	27	4	12/4/2001	5.3	0.74	16	6.4	12	389	248

Note: Bolded values are less than or equal to the lower 95 percent confidence limit for all parameters except pH and total alkalinity.

(a) Total Alkalinity and pH values reflect NaOH additions.

Table 3-31. Conventional Parameter Jar Test Results

Coagulant and Dose (mg/L)	Trial Number	Temperature (° C)	Sample Date	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L as CaCO ₃)	pH (pH Units)	Total Alkalinity (mg/L as CaCO ₃)	Specific Conductance (µmhos/cm)	Total Dissolved Solids (mg/L)
Untreated		Mean		6.9	3.2	31	7.0	18	384	278
Control		Mean		6.5	2.8	28	7.0	19	389	293
Control		95% Confidence Interval Limit		6.1 to 7.0	2.4 to 3.1	25 to 30	6.8 to 7.1	17 to 21	367 to 411	265 to 321
Pass C (continued)										
250	27	4	12/4/2001	6.34	1.74	23	6.2	8	433	240
5	28	15	12/4/2001	6.43	2.76	27	7.2	22	378	308
20	28	15	12/4/2001	6.57	2.73	28	7.0	20	371	300
50	28	15	12/4/2001	5.54	1.51	20	6.8	14	380	256
100	28	15	12/4/2001	4.89	0.60	15	6.5	10	391	204
250	28	15	12/4/2001	5.53	0.66	17	6.5	12	439	284
Superfloc A1849										
1	33	4	12/11/2001	6.07	2.03	24	6.8	10	457	208
1.5	31	4	12/11/2001	6.07	2.11	24	6.8	14	441	216
2.5	31	4	12/11/2001	5.42	1.60	20	6.8	14	444	200
3.5	31	4	12/11/2001	5.00	1.23	18	6.8	14	456	212
1.5	32	15	12/11/2001	5.16	1.38	19	6.8	12	445	186
2.5	32	15	12/11/2001	5.38	1.49	20	6.8	14	445	204
Westchlor 950S										
5	31	4	12/11/2001	7.05	3.14	31	6.8	12	444	220
20	23	4	11/28/2001	7.03	2.98	30	6.9	16	390	296
20	31	4	12/11/2001	7.21	3.21	31	6.7	12	445	164
50	23	4	11/28/2001	5.1	0.77	16	6.4	16	397	272
50	31	4	12/11/2001	5.29	0.95	17	6.5	8	457	216
55	23	4	11/28/2001	5.14	0.72	16	6.8	18	396	272
100	23	4	11/28/2001	6.99	2.70	29	6.7	8	416	284
250	23	4	11/28/2001	7.5	3.06	31	6.0	6	456	272
2	29	15	12/10/2001	7.51	3.62	34	6.8	14	419	272
5	29	15	12/10/2001	7.20	3.34	32	6.7	12	382	300
20	29	15	12/10/2001	7.37	3.63	33	6.7	14	377	316
50	29	15	12/10/2001	5.25	0.82	17	6.4	10	402	252
100	29	15	12/10/2001	6.73	1.98	25	6.1	8	426	428

Note Bolded values are less than or equal to the lower 95 percent confidence limit for all parameters except pH and total alkalinity.

(a) Total Alkalinity and pH values reflect NaOH additions.

3.6.1 Aluminum Sulfate (Alum) Treatment

Aluminum sulfate doses greater than 5.0 mg/L required the use of NaOH for pH adjustment. Therefore, the alkalinity results shown in Table 3-31 reflect the net effect after the addition of both aluminum sulfate and NaOH. The relationship between alkalinity and pH is illustrated by the results of these jar tests; in general, lower alkalinity correlates with lower pH.

3.6.2 Ferric Chloride Treatment

Ferric chloride doses greater than 20 mg/L required the use of NaOH to maintain pH between 6.0 and 7.0, as discussed previously. When more than sufficient base was added to maintain pH between 6.0 and 7.0, there was no reduction in alkalinity observed.

3.6.3 JC 1670 Treatment

There was no apparent correlation between JC 1670 dose and alkalinity.

3.6.3 Pass C Treatment

Pass C appeared to consume alkalinity. Supernatant alkalinity values dropped with increasing coagulant dose.

3.6.4 Superfloc A1849 Treatment

Superfloc A1849 did not show a significant effect on alkalinity.

3.6.5 Westchlor 950S Treatment

Alkalinity decreased as Westchlor 950S dose were increased, with the lowest alkalinities occurring at the highest doses.

3.6.6 Conventional Parameters Summary

The most important performance parameters from the conventional parameter group is alkalinity. Coagulant treatments resulting in the highest residual (supernatant) alkalinities are considered best. Alkalinity results for coagulant treatments are summarized and ranked at 4°C and 15°C in Tables 3-32 and 3-33, respectively.

Table 3-32. Alkalinity Relative Rankings: 4°C

Coagulant	Dose (mg/L)	Total Alkalinity (mg/L as CaCO ₃)	Alkalinity Rank
Aluminum Sulfate	100	14 (a)	-
Ferric Chloride	100	20 (b)	-
JC 1670	20	20	1
Pass C	100	12	3
Superfloc A1849	2.5	14	2
Westchlor 950S (c)	50	12	3

Notes: Bolded values are less than or equal to the lower 95% confidence limit for the control samples for parameters not adjusted experimentally.

(a) Required 0.3 mL of 1.5 M NaOH addition.

(b) Required 0.4 mL of 1.5 M NaOH addition.

(c) Average of two 50 mg/L dose results.

Table 3-33. Alkalinity Relative Rankings: 15°C

Coagulant	Dose (mg/L)	Total Alkalinity (mg/L as CaCO ₃)	Alkalinity Rank
Aluminum Sulfate	100	10 (a)	-
Ferric Chloride	100	10 (b)	-
JC 1670	20	12	2
Pass C	100	10	3
Superfloc A1849	2.5	14	1
Westchlor 950S	50	10	3

Notes: Bolded values are less than or equal to the lower 95% confidence limit for the control samples for parameters not adjusted experimentally.

(a) Required 0.3 mL of 1.5 M NaOH addition.

(b) Required 0.4 mL of 1.5 M NaOH addition.

3.7 Summary for Jar Tests Conducted at 4°C and 15°C Degrees C

The ranking sums by coagulant group and temperature for the optimum doses of coagulants tested are presented in Table 3-34. The ranking sums represented the total aluminum, filtered and total metals, nutrient (total TKN and total phosphorous) , total iron, and turbidity. These sums were obtained by comparison of the test results obtained from the 4°C and 15°C jar test experiments conducted using Batch III storm water. These individual temperature specific ranking sums were then added to obtain temperature-specific ranks. The temperature specific ranking sums are presented in Table 3-35. The 4°C and 15°C ranking sums are added together and this sum, then, is ranked to obtain the overall variable temperature ranking. The ranking of the variable temperature results indicate that Pass C dosed at 100 mg/L and Westchlor 950S dosed at 50 mg/L are the two most promising coagulants. However upon closer inspection of the analytical result differences and mass reductions are considered, then Pass C dosed at 100 mg/L is the superior coagulant.

Table 3-34. Summary of Ranking for Chemicals Tested at 4°C and 15°C

Coagulant	Dose (mg/L)	Temperature (degrees C)	Aluminum Ranking	Metal Ranking Sum	Nutrient Ranking Sum	On-Site Turbidity Ranking	Iron Ranking	Ranking Sum	4°C and 15°C Ranking
Aluminum Sulfate	100	4	5	30	10	4	3	52	5
Ferric Chloride	100	4	2	42	5	3	6	58	3
JC 1670	20	4	6	31	10	6	5	58	6
Pass C	100	4	3	20	3	2	1	29	2
Superfloc A1849	2.5	4	4	42	10	5	4	65	4
Westchlor 950S	50	4	1	18	4	1	2	26	1
Aluminum Sulfate	100	15	6	28	6	5	5	50	5
Ferric Chloride	100	15	5	41	8	6	6	66	6
JC 1670	20	15	1	10	6	1	2	20	1
Pass C	100	15	2	21	5	2	1	31	2
Superfloc A1849	2.5	15	4	31	8	4	4	51	4
Westchlor 950S	50	15	3	16	9	3	3	34	3

Table 3-35. Variable Temperature Study Ranking Summary

Coagulant	Dose (mg/L)	4°C Ranking Sum	15°C Ranking Sum	Ranking Sum	Variable Temperature Ranking
Aluminum Sulfate	100	52	50	102	4
Ferric Chloride	100	58	66	124	4
JC 1670	20	58	20	78	3
Pass C	100	29	31	60	1
Superfloc A1849	2.5	65	51	116	6
Westchlor 950S	50	26	34	60	1

Chapter 4

Jar Tests Conducted at 4°C With Storm Water Containing Higher Salinity and Phosphate Concentrations

Chapter 4 Jar Tests Conducted at 4°C With Storm Water Containing Higher Salinity and Phosphate Concentrations

The phosphorous and orthophosphate concentrations in the Batch III storm water collected at the Caltrans South Lake Tahoe Maintenance Station in Meyers were low to non-detect. To evaluate the potential for the coagulants tested to remove phosphate from storm water, a phosphate-spike study was conducted. Dibasic orthophosphate (H_2PO_3) was used to spike the storm water, increasing the phosphate concentration in the storm water by 1 mg/L as P. The form of phosphate added was different than might be expected in storm water (i.e., higher fraction of phosphate to total phosphorous). To evaluate coagulant performance phosphate was added because organic forms of phosphorous were not readily available for addition. After addition, the phosphate reacted with some constituents in storm water, thereby potentially mitigating some of the artifacts of the phosphate fraction increase (see Appendix E for additional discussion).

There was insufficient Batch III storm water to complete the phosphate-spike study so additional storm water was obtained from the storm water basin located at the South Lake Tahoe (Meyers) Maintenance Station. The storm water used for this study was collected on 12 December 2001 (Batch IV). Based on field and laboratory monitoring, the specific conductance of Batch IV storm water was significantly higher than Batch III, as discussed previously. The average specific conductance of the Batch III storm water (a blend of Batch I and Batch II storm water) differed from Batch IV storm water by more than an order of magnitude. The sodium and chloride concentrations in the Batch IV storm water were also very high, as indicated in Table 4.1.

Table 4-1. Comparison of Salinity Parameters between Batch III and IV Storm Water

Batch	Specific Conductance ($\mu\text{mhos/cm}$)	Total Dissolved Solids (mg/L)	Sodium (mg/L)	Chloride (mg/L)
Batch III	393	296	103	146
Batch IV	9,135	7,936	2,465	4,610

The original study plan was to compare jar test results using recent phosphate P-spiked results with earlier Batch III jar tests results. The specific conductance difference, however, would invalidate that comparison. Accordingly, jar testing with Batch IV water was done both with and without the phosphate spike. The additional advantage of this approach is that comparisons are allowed between “unspiked” Batch III and Batch IV jar tests, which may

show the effects of salt on coagulant performance (see Section 4.2). The concentrations of the coagulants used in the phosphate-spike experiments were selected based on the turbidities observed during the 4°C and 15°C experiments.

4.1 Phosphorous Removal

Results from the phosphate-spike jar test experiments, all done at 4°C, are shown in Table 4-2. Based on the data presented in Table 4-2, aluminum sulfate, ferric chloride, and Pass C are the most effective chemicals at removing phosphate from solution, while Superfloc A1849, JC 1670, and Westchlor 960S had very little effect.

Table 4-2. Comparison of Selected Parameters between Batch III and IV Storm Water

Coagulant	Dose. (mg/L)	Phosphate added (mg/L)	Orthophosphate, as P (mg/L) Total	Orthophosphate, as P (mg/L) Filtered	Phosphorous, as P (mg/L) Total	Phosphorous, as P (mg/L) Filtered
Untreated	0	0	0.24	ND	0.39	0.06
Untreated	0	0	0.15	ND	0.40	0.03
Control (unspiked)	0	0	0.05	ND	0.36	0.03
Aluminum Sulfate	100	0	0.07	ND	0.28	0.03
Ferric Chloride	100	0	0.25	ND	0.29	ND
JC 1670	20	0	0.03	ND	0.10	0.05
Pass C	100	0	0.03	ND	0.06	0.03
Superfloc A1849	2.5	0	ND	ND	0.17	0.04
Westchlor 950S	50	0	0.04	ND	0.08	0.05
Control (spiked)	0	1	0.80	0.58	1.42	0.93
Aluminum Sulfate	100	1	0.30	0.03	0.65	0.05
Ferric Chloride	100	1	0.21	ND	0.30	0.03
JC 1670	20	1	0.65	0.42	0.85	0.71
Pass C	100	1	0.21	ND	0.30	0.05
Superfloc A1849	2.5	1	0.75	0.40	1.44	0.97
Westchlor 950S	50	1	0.54	0.39	0.65	0.42
Reporting Limit			0.03	0.03	0.03	0.03

The relative rankings of the coagulants by phosphorous species are presented in Table 4-3 (phosphate) and in Table 4-4 (phosphorous).

Table 4-3. Phosphate-Spike Experiment Phosphate Relative Rankings Summary

Coagulant	Dose (mg/L)	Orthophosphate as P (mg/L) Total	Orthophosphate, Ranking Total	Orthophosphate as P (mg/L) Filtered	Orthophosphate, Ranking Filtered
Aluminum Sulfate	100	0.30	3	0.03	3
Ferric Chloride	100	0.21	1	ND	1
JC 1670	20	0.65	5	0.42	6
Pass C	100	0.21	1	ND	1
Superfloc A1849	2.5	0.75	6	0.40	5
Westchlor 950S	50	0.54	4	0.39	4

Table 4-4. Phosphate-Spike Experiment Phosphorous Relative Rankings Summary

Coagulant	Dose (mg/L)	Phosphorous, as P (mg/L) Total	Phosphorous Ranking Total	Phosphorous, as P (mg/L) Filtered	Phosphorous, Ranking Filtered
Aluminum Sulfate	100	0.65	3	0.05	2
Ferric Chloride	100	0.30	1	0.03	1
JC 1670	20	0.85	5	0.71	5
Pass C	100	0.30	1	0.05	2
Superfloc A1849	2.5	1.44	6	0.97	6
Westchlor 950S	50	0.65	3	0.42	4

The overall phosphorous rankings indicate that ferric chloride, Pass C, and aluminum sulfate were the three best coagulants for removing phosphorous (all forms) from the storm water tested. The ability of Pass C to remove phosphorous from storm water without the addition of alkalinity was deemed superior; and therefore, these findings confirmed that Pass C dosed at 100 mg/L was the best coagulant and dose tested.

4.2 Salinity Effects

Salinity changes occur seasonally in the mountainous areas of California, including the Lake Tahoe Basin because salt mixed with sand and applied to roadways during winter months when ice and snow are present improves the safety of roads for travel. As discussed previously, the effects of salinity was not a variable affecting coagulant performance that was planned for study. The dose of each coagulant that best removed solids was tracked throughout the study. Other pollutant removal performances point to the same optimum dose for each coagulant studied. A comparison of selected solids parameters from Batch III and

Batch IV storm water jar tests conducted at 4°C is presented in Table 4-5 below to evaluate possible salinity effects.

Table 4-5. Batch III and Batch IV Storm Water Comparison of Coagulant Performance

Coagulant	Dose (mg/L)	Batch III Storm Water (low EC)			Batch IV Storm Water (high EC)		
		EC (µmhos/cm)	TSS (mg/L)	On-site Turbidity (NTU)	EC (µmhos/cm)	TSS (mg/L)	On-site Turbidity (NTU)
Untreated (a)	---	384	232	---	9,135	398	419
Control (b)	---	389	185	348	8,840	338	390
Aluminum Sulfate	100	481	67	80	9,200	282	268
Ferric Chloride	100	428	44	77	8,770	149	37
JC 1670	20	407	158	235	8,120	143	53
Pass C	100	389	42	36	8,710	116	16
Superfloc A1849	2.5	444	97	131	8,750	190	79
Westchlor 950S (c)	50	416	44	23	8,830	122	28

- (a) The untreated mean for Batch III storm water was obtained using seven samples (see Appendix D). The untreated mean for Batch IV was obtained using two samples (see Appendix E).
- (b) The control mean for Batch III storm water was obtained using six samples (see Appendix D). The control result shown for Batch IV storm water was for the “unspiked phosphate” sample (see Appendix E).
- (c) The Westchlor 950S data for Batch III storm water was the average of the three Westchlor 950S results (2-50 mg/L and 1-55 mg/L dose) from jar tests conducted at 4°C.

Low and high salinity storm water have different relationships between turbidity and total suspended solids as shown in Table 4-5. For similar turbidity values, the total suspended solids concentration is lower in the Batch III storm water samples than in the Batch IV storm water samples. The data indicate that storm water constituents contributing to total suspended solids (larger than 0.45 µm) under high salinity conditions have relatively little affect on turbidity. Whether this phenomenon is real or an artifact of laboratory analyses delays cannot be determined based on available information. Under high salinity conditions such as would occur during and after road salting events, Pass C at a dose of 100 mg/L was most effective at reducing turbidity and total suspended solids concentrations.

Chapter 5

Summary Discussion

Chapter 5 Summary Discussion

The variable temperature experimental results were used to select the coagulant and concentration for use in the Lake Tahoe Small-Scale Storm Water Treatment Pilot Study. The rankings for the variable temperature results are presented in Tables 5-1 and 5-2. Table 5-3 presents the rankings by chemical and temperature. The “chemical addition” category was scored based on whether or not sodium hydroxide addition was necessary to supply alkalinity for coagulation/flocculation and to maintain pH. If a chemical concentration required the addition of sodium hydroxide (NaOH) a score of six was assigned, and if not, a score of one was assigned. The aluminum, metals, nutrients and on-site turbidity were ranked by concentration, lowest (1) to highest (6). Only the ranking for the best performing concentration in each case is presented.

Table 5-1. Ranking Summary: 4°C

Coagulant	Dose (mg/L)	Chemical Addition	Aluminum	Metals	Nutrients	On-Site Turbidity	SUM	Overall 4°C Ranking
Aluminum Sulfate	100	6	5	3	4	4	22	6
Ferric Chloride	100	6	2	5	3	3	19	4
JC 1670	20	1	6	4	4	6	21	5
Pass C	100	1	3	2	1	2	9	2
Superfloc A1849	2.5	1	4	6	4	5	20	3
Westchlor 950S	50	1	1	1	2	1	6	1

Table 5-2. Ranking Summary: 15°C

Coagulant	Dose (mg/L)	Chemical Addition	Aluminum	Metals	Nutrients	On-Site Turbidity	SUM	Overall 15°C Ranking
Aluminum Sulfate	100	6	6	4	2	5	23	5
Ferric Chloride	100	6	5	6	4	6	27	6
JC 1670	20	1	1	1	2	1	6	1
Pass C	100	1	2	3	1	2	9	2
Superfloc A1849	2.5	1	4	5	4	4	18	4
Westchlor 950S	50	1	3	2	6	3	15	3

Table 5-3. Jar Test Study Relative Ranking Summary

Coagulant	Dose (mg/L)	4 °C Ranking Sum	15 °C Ranking Sum	Ranking Sum	Relative Ranking
Aluminum Sulfate	100	22	23	45	5
Ferric Chloride	100	19	27	46	6
JC 1670	20	21	6	27	3
Pass C	100	9	9	18	1
Superfloc A1849	2.5	20	18	38	4
Westchlor 950S	50	6	15	21	2

This summary ranking methodology was based solely on the overall rankings for each category. This summary ranking methodology is a more general approach than the ranking methodology used to summarize the variable temperature results, which was based on ranking sums for those pollutant categories having more than one ranking criteria. Use of multiple ranking strategies provided a robust environment for comparison of coagulant performances. The results of the comprehensive jar test experiments demonstrate that Pass C dosed at 100 mg/L performed best with regard to overall pollutant removal ability.

Chapter 6

Conclusions

Pass C dosed at 100 mg/L was the highest ranked coagulant based on the variable temperature jar test experiments. Pass C at 100 mg/L also performed well in the phosphate spiked experiments with one of the highest overall phosphorous removal ranking.

Chapter 7

References

Chapter 7

References

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